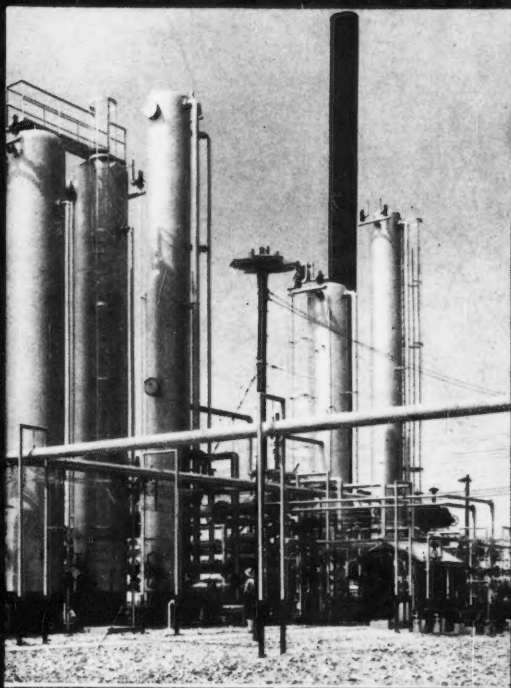


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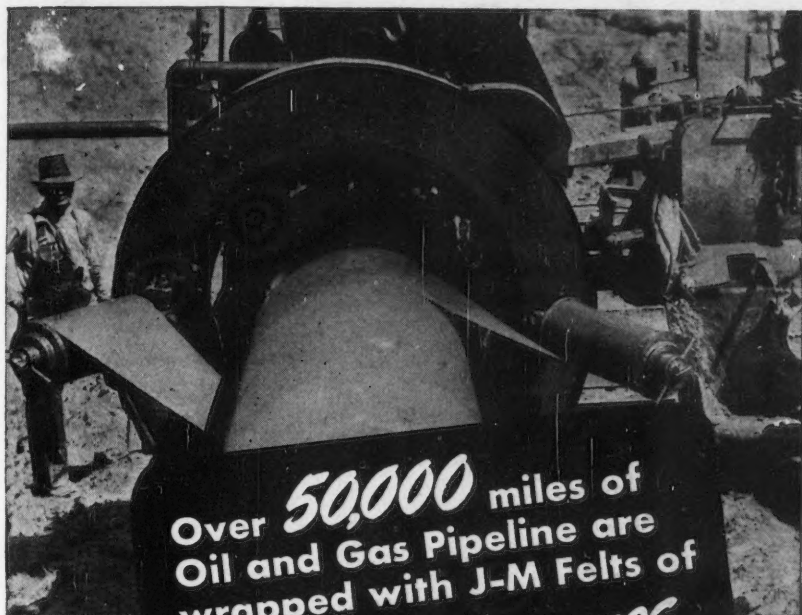


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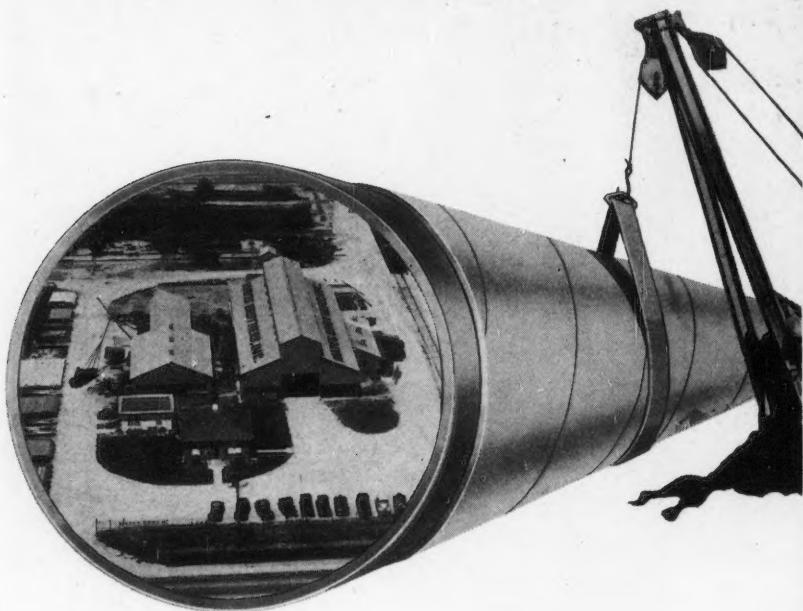
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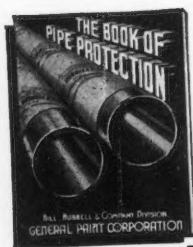
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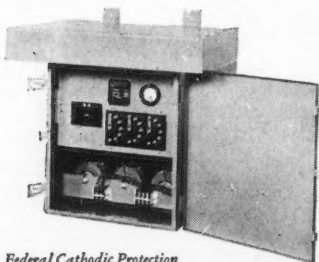
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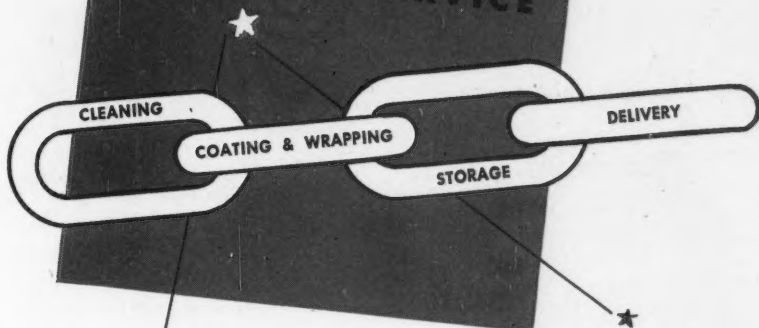


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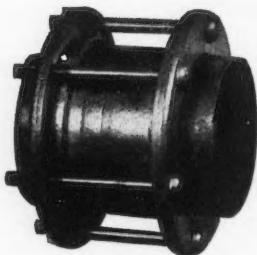


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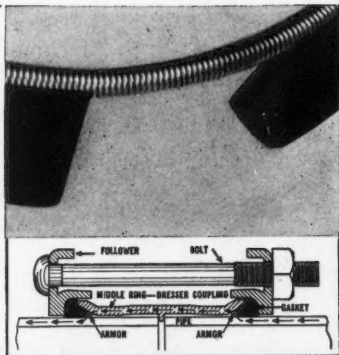
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**An Official Publication of the
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CORROSION ENGINEERS**

A quarterly publication—to provide in permanent record the papers prepared for the Association, at meetings, annual conventions and from editorial sources.

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Purposes of the Association

The National Association of Corrosion Engineers was founded to bring together in one organization all those engineers engaged in corrosion work.

The first consideration was whether such an organization was needed and whether some existing organization might carry on the work contemplated. Most engineering societies, trade associations, and similar organizations have committees, sections, or divisions devoted to the solution of the corrosion problems encountered by their members. Some of these organizations have sections which include, or could include, in their membership representatives of a large proportion of all industry. It was the decision of the founders, however, that the need for coordinating the efforts of those engaged in the work of determining the best methods of corrosion prevention or control and of adapting the methods developed to actual problems was so great that a separate association devoted exclusively to the accomplishment of this coordination was justified.

In order to accomplish its purpose of providing a means of coordinating the efforts of all individuals actively engaged in the control of corrosion of metallic structures, the NACE proposes to establish and maintain such organizational facilities as may be required. Perhaps the principal of these facilities will be the holding of annual meetings where technical papers will be presented. The presentation of these papers and the discussion of them should be of great benefit to both the contributors and to those in attendance. The opportunities for making personal acquaintance with other workers in related fields and for informal discussion of problems are offered only at meetings such as we propose to hold. It is likely that exhibits of materials and equipment will be held in conjunction with the meetings at some time in the future with the result that added benefits will be derived from attendance at the meetings.

Another of the organizational facilities which the Association proposes to maintain is the publication of a journal. This issue of CORROSION is the beginning of a journal devoted to the presentation of technical articles and news of interest to members. The chief source of the technical articles will be the papers presented at annual meetings but other high grade articles will be published as they become available. After local sections of the Association are set up, papers from sectional meetings can be published in the journal. It is proposed that a high standard of technical excellence be maintained in all of our publications.

The NACE has as one of its purposes the encouragement of joint action by its members in solving specific corrosion problems. This encouragement may take the form of appointing committees to investigate and report on special problems, or programs of investigation and testing may

be formulated and the coöperation of members and interested parties obtained in carrying out the programs. The NACE would coördinate such work as this through the office of its executive secretary. The Association may also sponsor special investigations in which contributions are made by interested parties and research workers are engaged by the Association to seek solutions to the problems. Unbiased reports giving the results of these investigations could be released in the name of the Association. It is also proposed that the NACE shall coöperate with other organizations in corrosion work.

The form of organization which can successfully set up and maintain these facilities is a matter which has been given and must yet receive a great deal of attention. At the time this is being written, a committee is making a study to determine what changes in our form of organization should be recommended. The principal purpose of the Association has always been and must continue to be the coördination of the efforts of *all* persons engaged in the investigation of the causes of corrosion and the development of methods of its control. The accomplishment of this purpose requires that membership shall be on an individual basis and that membership fees shall be moderate. It is also required that the widest possible exchange of ideas between members shall be accomplished. It has been demonstrated by other organizations as well as by our own experience that the necessary organizational facilities cannot be provided for a large, widely dispersed membership from the funds available from individual membership dues. Consideration is therefore being given to the possibility of obtaining additional funds by offering sustaining memberships to companies. The fact that some companies, in both supplier and user groups, will receive benefits from the existence of this Association far out of proportion to the contributions to it by their employees who are members should make them willing to support its work by becoming sustaining members.

The establishment of local sections must be provided for in a country as large as ours, and no doubt sections will be established in other countries as more members are enrolled. It may also be advisable to establish industrial divisions for, while all corrosion problems are fundamentally the same and workers in one industry or field can give ideas to those in other industries or fields, the particular phase of the problem in one industry might be so unique that it would be of interest only to those immediately concerned.

The form which our organization will take has not yet been set but it will be molded to fit our purpose of coöordinating the efforts of corrosion engineers in reducing the losses due to corrosion. The best efforts of all members in perfecting the organization are earnestly solicited.

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Volume 1

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Corrosion Research and Abatement — Yesterday and Today

By Frank N. Speller
Metallurgical Consultant

TECHNICAL literature contains relatively few references to corrosion research prior to 1900. Prior records and the work done in the first few years of this century deal mostly with the relative corrosion of wrought iron, cast iron and steel. These questions for some time led to heated arguments rather than to research. The fact, not then recognized, seems to be that wrought iron on account of its rough finish makes for better adhesion of mill scale and paint, and, therefore, better results are observed in the atmosphere. The presence of a small amount of copper, in the light of later knowledge, accentuated this difference but the advocates of wrought iron insisted that the two or three per cent residual silicate cinder in the forged iron obstructed the course of corrosion.

The differences between corrosion in air and water were not then known. Corrosion was regarded as one problem whereas we now know that it involves many problems all connected by certain well established fundamental principles. Thus a controversy was kept up for many years between those who accepted the traditional belief that wrought iron was inherently more durable than steel and those who were slowly accumulating data from controlled tests that did not indicate any material difference where the bare metals were exposed to air or water.

In 1903 Whitney (1) demonstrated that the primary cause of corrosion was electrochemical and in 1907 W. H. Walker showed that the corrosion reaction is continued by depolarization of the cathode which is usually brought about by the combination of dissolved oxygen with the atomic hydrogen film deposited on the metal. The research by W. H. Walker and his associates in Massachusetts Institute of Technology (2) and of Ulick R. Evans in England during the next few years contributed much to our knowledge of the influence of the factors that dominate the rate and distribution of corrosion.

In the light of the new electrochemical theory a few jumped to the conclusion that maximum homogeneity and purity of the metal would greatly prolong the life of steel if it did not solve most of the corrosion problems. This resulted in a curious and amusing fight for several years between those who advocated iron speckled with two or three of the cinders necessarily formed in the refining operation, and those who advocated and sold commercially pure iron (99.8%) low in carbon and manganese and free from all but a trace of oxides (except alumina, formed in the open hearth refining process, which was not so easy to eliminate).

In 1905 the American Society for Testing Materials organized Com-

mittee A-5 in Corrosion of Ferrous Metals to conduct fact-finding tests. In 1922 Committee B-3 was organized and now is carrying on field tests on non-ferrous metals. The results of these extensive tests are fully described in the annual reports of these Committees.

In 1900 Williams (3) from some limited laboratory tests concluded that copper lowered the rate of corrosion of iron under certain conditions. The subject was not followed up until D. M. Buck made extensive tests out-of-doors several years later. In 1911 the American Sheet & Tin Plate Company, whom Buck served so efficiently, announced low carbon steel containing 0.15 to 0.25% copper as a commercial product. In 1913 Buck reported the results of his weather tests which indicated that the life of copper-bearing steel was at least double that of the same steel without copper. He later found that as little as 0.05% copper had a substantial influence. (4)

In 1916 Committee A-5 of the ASTM started extensive field exposure tests on full-sized sheets of Bessemer and open hearth steel, pure iron and wrought iron, each with high and low copper. By 1930 the results pointed definitely to the conclusion that the useful life of iron was considerably extended when it contained over 0.15% copper. Later tests in water and soil on the contrary showed that the good influence of copper applied only under certain atmospheric conditions and was not found in water or soils.

These and other tests during the next 15 years or so clearly showed that the environment usually controls the rate of corrosion, especially of carbon and low-alloy steels or

wrought iron, rather than the composition, particularly in water or soil. In water there are a few exceptions to this rule such as 3% chromium steel which has about twice the durability of low-carbon steels in fresh water and sea water. Tests for several years in sea water indicate that pits develop less rapidly in low alloy steels than in carbon steels. Steels with 12% or more of chromium and stainless steels of the 18-8 class have a very low rate of loss in weight in most waters, but in corrosive soils often suffer highly localized attack, especially where concentration cells occur on the metal surface. Nickel clad steel was first commercially produced and marketed in 1930. About four years later chromium-nickel clad steel was produced and cupro-nickel clad followed two years afterward. During the same period silver clad and all grades of stainless clad steels were produced. Aluminum clad is another important development in the same line that prolongs the life of aluminum alloys.

From these developments it was evident that practically all ordinary commercial steels and some non-ferrous metals would usually have to be protected by other than metallurgical means, in corrosive soils and in water. (5) This led to the study of better protective coatings, treatments that could be applied economically to industrial and potable waters, and more recently to cathodic protection.

The entry of the American Petroleum Institute into coöperative study of corrosion problems of the oil industry in 1924 marked the beginning of a definite advance in the study of these problems. In the

transportation field this work was furthered, as you know, by the coöperation of the National Bureau of Standards and by parallel investigations of the Natural Gas Industry on underground protective measures.

In selecting the preventive measure that seems best adapted for any specific case, it is usually only necessary to consider the inhibiting effect and cost spread over the expected or useful life of the metal compared with the cost of repairs and replacement and loss due to reduction in service capacity during the life period of the system. Prevention of these diseases of metals differs from therapeutics in that respect; in both, however, prevention is better when applied before the trouble is in the advanced stages.

It would require another book to describe all the important developments in corrosion protection during the past 40 years, so I will attempt to discuss briefly only a few of the typical milestones on the road of progress in addition to those mentioned above.

Among the other outstanding achievements which directly or indirectly have led to the better protection of metals, we might list the following:

Mechanism of Corrosion: A clear understanding of the electrochemical principles of corrosion reaction and the causes of localized attack.

Corrosion and heat-resistant alloys; Ferrous and non-ferrous Clad-Metals; such as aluminum clad and steel clad with copper, nickel 18-8, etc.

Electro-Plating and Metal Spray improvements.

Soil Corrosion Research at Bureau of Standards and in coöpera-

tion with the API and AGA committees.

Pipe Coating improvements for exterior protection underground.

Centrifugally applied interior coatings for water mains.

Cement-lined water tanks and pipe.

Anaerobic Bacteria as accelerators of corrosion.

Cathodic Protection for exterior protection of pipe underground and interior of water tanks and other metal structures in sea water or fresh water.

Corrosion Fatigue, U. S. Naval Experimental Station, Annapolis, Md., and by members of the API committee and others.

Boiler Water Treatment

Boiler Cracking by stress-corrosion, Merica (1914), Paur and Straub (University of Illinois, 1926) Joint Research Committee on Boiler Water Studies in coöperation with the U. S. Bureau of Mines 1932-42.

Steam Heating under N.D.H. Assn. and A.S.H. & V. Eng.

Deaeration of cold and hot water.

Water soluble corrosion inhibitors.

All of these deserve more than mere mention, but I shall discuss only a few, of which I believe we shall probably hear much more in the near future.

Corrosion-Fatigue

The effect of stress concentration in rapidly developing fatigue cracks was first observed by Haigh in England about 1916. This was followed in 1923 by the exhaustive work by D. J. McAdams at the U. S. Naval Experimental Station. In 1927 work in the research laboratory of the

National Tube Company showed the marked effect of accelerators and inhibitors on corrosion fatigue as indicated by tests on the R. R. Moore machine (9) and in 1928 notable work was done in the research laboratory of the Gulf Development Company showing the reduction in endurance of metals and alloys in saline waters with and without H_2S , similar to those found in oil wells (10). An API committee was organized in 1936 and sponsored experimental work on corrosion fatigue of rotary drill pipe for four years (11).

Protective Coatings

The improvement in paints and lacquers for use under atmospheric conditions is well known to most of us. During the past ten years there has been a great improvement in paints for use in subaqueous environment. The work sponsored or carried on by the Tennessee Valley Authority, Panama Canal and U. S. Corps of Engineers on paints for protection of steel structures underwater, and the extensive tests maintained by leading manufacturers, have resulted in much longer service from such coatings under severe service conditions. Briefly this consists in a general recognition of the fact that the metal should be cleaned by sand or grit blasting (or pickling) and the first coat applied shortly afterwards when there is no danger of a film of moisture forming on the metal.

In the light of present experience for any specific underwater service the choice of a paint system would probably be among one of the phenolic resin-varnish vehicles pigmented with iron oxide, red lead, zinc chromate, blue lead, aluminum

or zinc-dust-zinc oxide, or chlorinated rubber with suitable pigmentation. Straight linseed oil paints soften and are not nearly so durable as the synthetic variety referred to when continuously wetted, but are better after several weeks of air drying before immersion. The paint systems which have generally given the best results are those based on phenolic resin varnishes of moderate oil-length, usually 25 gallons of oil to 100 pounds of phenolic resin. Tung oil by itself or with 40% linseed oil has given good results in this combination.

Phenolic base coatings of the baking type have recently given encouraging results after four years in low-pressure hot-water and steam heating boilers and promise to be useful as protection for heat exchangers. (These and other new synthetic resin materials no doubt will be more generally used for this and similar purposes when they become more generally available after the war.)

Now let us turn to the question of coatings for underground pipe lines. The coöperative tests cited above indicated the limitations of ordinary bituminous coatings reinforced with fabric, how they could be improved in material application, and the superiority of coal tar enamels and asbestos fabric for this type of coating. To secure adequate protection over the life of the line in very corrosive soils it is apparently necessary to use a much thicker coating, such as extruded asphalt mastic, or cathodic protection in combination with a durable reinforced bituminous coating. Many of you are living close to this problem and are quite familiar with the notable advance

that has been accomplished and what remains to be done. (15)

Refinery corrosion problems are well covered in the Proceedings of the API during the past 15 years and the able review by Ivy M. Parker at the first meeting of the NACE in April, 1943. However, some of the protective measures selected for more detailed discussion today obviously apply to refinery cooling waters.

Removal of Dissolved Oxygen

In his early investigations of the corrosion of water supply pipes the author observed a marked difference in internal damage of pipe in closed systems near the source of supply and farther away. This difference in rate was most noticeable in hot water systems and was evidently due to removal of free oxygen. The fact that, other things being the same, corrosion was nearly proportional to the dissolved oxygen contents was then established experimentally (5 p-386). Laboratory experiments in 1906 on removal of dissolved oxygen by contact with a large surface of iron scrap indicated the relationship between metal surface area and temperature. A plant test for removal of oxygen by contact with steel scrap for an hour or so at 150° F. (5 p-390) was installed in Pittsburgh in 1915. Quite a number of "deactivating" plants were constructed a few years later on this principle but while effective they generally proved to be rather troublesome to maintain and for large systems were bulky compared with the later vacuum deaerators.

The design of apparatus for removal of free oxygen required to prevent serious corrosion depends

mainly upon the temperature and amount of water passing through the system. At normal temperature it is usually not necessary to reduce the dissolved oxygen below 0.3 ppm. At 160° F. for hot-water systems the dissolved oxygen should be below 0.10 ppm; for low-pressure boilers without economizers .03 ppm. and for high pressure boilers practically zero oxygen is required. The minimum dissolved oxygen measurable by the most refined methods is about .005 ppm. Committee D XIX ASTM (Determination of Dissolved Oxygen). Dissolved gases (O, CO₂, H₂S and NH₃) can be eliminated from water, if the temperature and pressure conditions are so regulated that the gases become insoluble and mechanical conditions are favorable for their separation from the water.

The design of mechanical deaerating apparatus has been greatly improved and there are now several types of deaerator, each adapted for a specific kind of service.

Cold Water Deaeration

In 1917 the Coolgardie water supply in western Australia (6,000,000 G/D) was deaerated in two towers each with vacuum lines at their tops and capacities of 3,000,000 B/D. Little interest was shown in this method of controlling corrosion in once-through cold water systems in spite of the satisfactory results of the Australian venture until 1934 when the Freeport Sulphur Company installed a plant designed by S. T. Powell along similar lines. This also proved satisfactory and maintained the capacity of the steel main with a flow of 4,000,000 G/D. Several other plants have been built since then in which the water is

sprayed over wooden trays under about 28" vacuum usually maintained by means of two-stage steam jets. The cost of operating such a plant is little more than the cost of steam required to operate the vacuum jets and the cost of repumping the water if that is necessary.

Hot Water Deaeration

During the past ten years radical improvements have been made in the design of equipment for removing dissolved oxygen from hot water. In general there are now two types of mechanical deaerators in use, known as the Tray and Spray Systems. In the Tray apparatus the water passes first through a vent condenser then into a steam-heated section where it cascades down over metal trays in a storage space. This type of deaerator may be operated under pressure or vacuum.

The Spray type apparatus was originally designed primarily for marine service. The water is mechanically atomized by passing through special nozzles into an atmosphere of steam which fills the deaerator at about $1\frac{1}{4}$ pounds pressure.*

It consists essentially of a vent condenser; a steam heating section; a deaerating section, surrounding the steam inlet, and a storage section below. The water passes downward from the vent condenser in that order and enters the deaerating section. Steam passes upward in the reverse direction. A portion of the half bound CO_2 is released from bi-

carbonates in passing through the deaerator with an increase in the pH. Efficient deaerators have become an essential part of modern steam boiler equipment. They spray type deaerator which has recently shown such satisfactory results in marine service will probably find a wider use in stationary boiler service. Dissolved oxygen can be reduced to 0.005 cc/l or lower by this method. Several other designs are available for specific types of service on which the bulletins of the leading manufacturers may be consulted. Generally two grades are available; one with guaranteed 0.005 cc/l maximum oxygen and the other with a maximum of 0.03 cc/l.

The condensate from condensers in steam power plants at 80 to 100° F. has been deaerated to 0.02 cc/liter oxygen under a vacuum of about 29.5" Hg.

Inhibitors

A symposium of a dozen papers on inhibitors for control of scale and corrosion in water was sponsored by the American Chemical Society at its annual meeting September, 1944. These papers have been published (13) and give an outline of the present status of the subject both as to fundamental studies and application in practice.

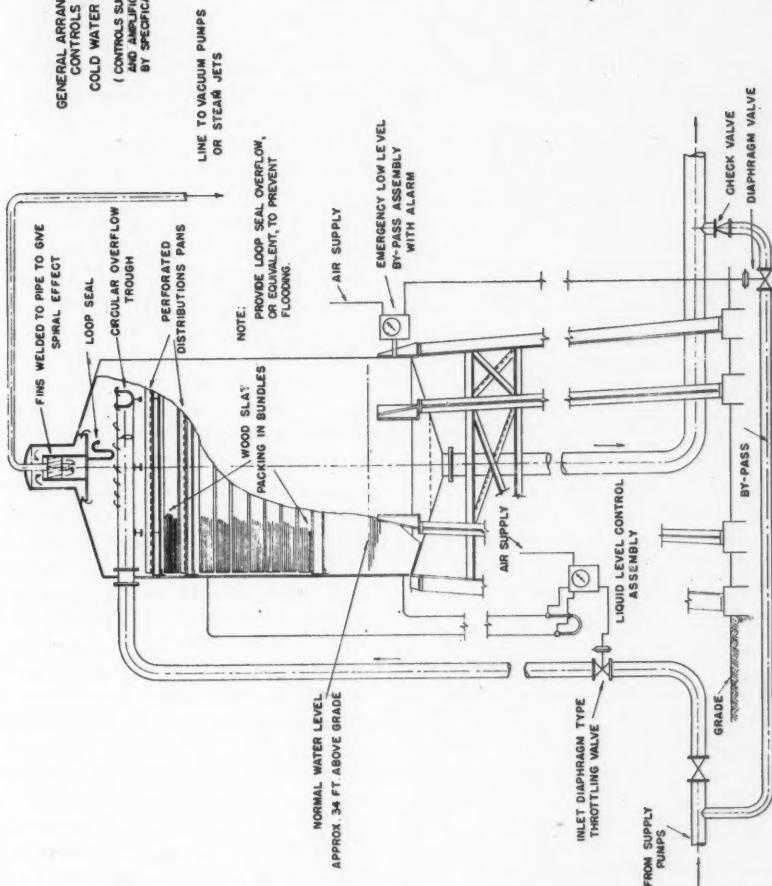
The best materials to use as inhibitors and the optimum concentration depends very much on the composition of the water solution, temperature and other factors, so only a general review of progress will be attempted here.

Perhaps the simplest inhibitive system is a deposit of calcium carbonate formed by adjusting the pH of the natural water with respect to

* Nearly complete deaeration of hot feed water for boilers was first accomplished by the Elliott Company in 1918 by spraying the heated water into a vacuum chamber.

FIGURE

GENERAL ARRANGEMENT OF PIPING AND
CONTROLS OF SINGLE STAGE
COLD WATER VACUUM DEAERATOR
(CONTROLS SUBJECT TO MODIFICATION
AND REVISION AS DICTATED
BY SPECIFICATIONS)



S.T. POWELL

the carbonates, bicarbonates, and free CO_2 (5 p-362). This system is used in some municipalities and often gives considerable protection in the cold water system but much less in hot water, unless the time scale so formed is relatively thick. In that case, however, it may seriously interfere with heat transfer. Objectionable deposits of scale of this kind may be prevented by the addition of 2 or 3 ppm of a polyphosphate** but serious hot water corrosion is likely to occur when the treated water contains much free oxygen unless another protective material is laid down in place of the scale. Increasing the phosphate feed to 8 or 10 ppm has shown promise of considerable protection in large hot water installations during the past year.

A recent paper by engineers in charge of treatment of potable water at U. S. Army Posts (13) reports results in control of scale and corrosion with several well-known inhibitors. This experience indicates at present that both of the polyphosphates control deposits of lime, iron and manganese satisfactorily. Control of corrosion is not so pronounced as scale prevention where the water is heated to 180°F . or higher. However, these and other compounds have not been used long enough to definitely determine their value as corrosion inhibitors under these conditions. The protection from these inhibitors is more marked on galvanized than on black iron. Silicate of soda or sodium chromate may be fed with the polyphosphate in a mixed solution (30% to 50%

concentration). Combinations of organic inhibitors, chromates and certain polyphosphates have also been used for this purpose. In some cases, combinations of these inhibitors have proved more effective than either one used separately, for example, the addition of meta silicate with chromate for the protection of aluminum (14).

Chromates

Following research sponsored by the National Tube Company (1918-1922), Inhibitors for refrigerating brine systems were investigated at M.I.T. (1922-1924), with a research committee of the ASRE. The committee finally recommended 1600 ppm sodium chromate for sodium chromate calcium brines and 3200 ppm for sodium brines (20% chloride concentration) (5 p-615). This (or chromic acid or sodium dichromate made alkaline to pH 8.5) is still quite generally used for the protection of bare steel and galvanized parts in these high chloride refrigerating solutions. Accelerated attack from contacts between dissimilar metals is also largely retarded by chromates. In brines the protection is not complete but the average rate of attack is reduced about 90% and serious pitting has not been encountered, perhaps due to the precipitation of calcium oxychloride on the cathode areas (14).

Chromate solutions have certain limitations; they have an irritating effect on the skin of some people, but this can be largely prevented by thorough washing shortly after the contact. Sodium chromate (valence 6) is reduced by some organic materials to the chromic salt (valence 3), which has very little inhibiting

** The term polyphosphate is used here for hexameta or septaphosphate of sodium.

value. The rate of reduction is often quite slow but the chromate should be checked regularly. It is therefore advisable to avoid contaminating the inhibited water with humus or other organic materials. In spite of these disadvantages the chromates have had a long and useful record in treatment of brines and industrial waters. Anodic inhibitors like the chromates may cause sharp pitting when the concentration is insufficient to entirely prevent corrosion. This tendency towards pitting (with or without inhibitors may be prevented or restrained by rubbing off the incipient tubercles of rust. The rubber disc swabs used to clean petroleum product lines probably have this effect and also tend to force the inhibitor more uniformly onto anodic areas. Frequent cleaning of condenser and heat exchanger tubes is recommended for the same reason, even though the overall average corrosion loss is slightly increased thereby. The presence of another inhibitor with one that is distinctly anodic in action has given better protection. For example, the favorable results cited from treatment of commercial brines with chromate and the use of mixtures of polyphosphates and silicates in natural waters.

Most of you are familiar with the application of inhibitors that was developed for oil product pipe lines about ten years ago. A marked reduction in flow capacity was noticed due to the rough rust scale on the interior surfaces. This corrosion is due to the presence of a small amount of water deposited on the metal with free oxygen, both derived mainly from the lighter petroleum products in transit. A satisfactory

remedy has been found by excluding entrained water and using suitable inhibitors with occasional swabbing by rubber discs. As the amount of water entering the line cannot be predicted and varies considerably in quantity and composition it is necessary to add a large excess of the inhibitor. Sodium chromate was first applied to product lines about 9 years ago and sodium nitrate was developed especially for that purpose, a few years later. The latter may find wider application in corrosion problems in industrial waters (16). Both the chromate and nitrite treatment have given satisfactory results in new and old rusted oil product lines. The water in the line should be limited strictly to that deposited from solution in the products carried by the line. As pointed out above, the rubber swabs apparently bring the inhibited water into more intimate contact with the metal and tend to check any tendency to localized attack. The International Nickel Company tested the effect of rubbing at the writer's suggestion in connection with a Panama Canal corrosion problem (13 Copson). Bayonne, N. J., city water (which is similar in composition to the Panama fresh water) was treated with 300 ppm sodium chromate pH 8 and slightly agitated. Clean nickel-iron couples were exposed in this water for 56 days. One set of these specimens was rubbed every two weeks, the other was not touched. Small rust tubercles developed on the polished iron that was not rubbed but the rubbed specimens remained smooth and free from any corrosion. In fresh Canal water chromate was not so effective evidently due to its reduction by or-

ganic matter in the water and the higher temperature at Panama. The flow capacity of gasoline pipelines has also been maintained by swabbing every five days without the addition of an inhibitor.

Inhibitors for Potable Waters

About 1920 the author noticed that silica was often found as one of the constituents in the protective deposits in water pipe (5 p-359). Certain proprietary water treating compounds containing sodium silicate had no doubt been sold and used before this. Later in 1922 Thresh found that the addition of silicates greatly retarded corrosion of lead and iron water pipe and thereby prevented lead poisoning. The protective layer in this case seems to be a silica gel formed by the negatively charged colloidal silica particles being attracted to the positively charged metal ions on the metal surface. This gel is of visible thickness and forms more readily on galvanized than on plain iron. (13 Stericker). An excess of silica (over that present in the natural water) of 20 ppm is usually desirable in starting this treatment which may be reduced to 8 or 10 ppm after a month or so. The most favorable treatment should be determined for any particular water. Silica treatment usually gives from 50% to 70% protection and is applicable to most of the soft or medium hard waters. It is effectively used in New York City and other locations for prevention of dezincification of brass pipe as well as for the protection of plain galvanized iron and steel pipe. Intermittent treatment is satisfactory in some waters.

Summary

From this brief and incomplete outline of preventive measures it is evident that relatively little improvement can be expected in the useful life of ordinary bare ferrous metals now in use without considerable extra cost. Much metallurgical experimental work was done on that phase of the subject prior to 1920. More uniform corrosion was obtained under some conditions by better surface finish but as experience accumulated it became more evident that localized attack, which is usually the cause of failure in service, was generally due to external contact effects such as concentration cells. Metals such as stainless steels have the innate power to form self healing films and protect against many types of corrosion, but no commercial metal can be expected to resist all types of corrosive attack (7). It, therefore, was soon evident that the most economical remedy in the case of ordinary ferrous metals lay in protective coatings, cathodic protection, deaeration of water and inhibitors or deactivators, all of which tend to protect the metal from destructive environment.

Many of these remedies, such as the limited number of water soluble inhibitors that are permissible for domestic water, are far from satisfactory but the effect of them is much better than no treatment. This is an inviting field of research which some day should produce much better results.

Work on a problem of such wide interest as corrosion should benefit by simple organization. Research has multiplied many fold during the past

30 years. Prior to 1904 not more than half a dozen men in this country were devoting much of their time to this subject. Now the study and control of corrosion provides work for several hundred engineers and investigators.

The first step in organizing the many widely scattered interests was completed in 1938 when the American Coördinating Committee on

Corrosion was organized in Philadelphia. The main committee consists of a representative from each association or society which desired to participate. It now includes representatives from 18 national groups each of whom contributes financially toward the clerical expenses. At present the secretary's office is at 4400 Fifth Ave., Pittsburgh, Pa. (Mellon Institute).

TABLE 1
Facilities for Corrosion Studies*

Atmospheric Test Sites				Alternate Immersion (Half Tide):			
These are highly concentrated in the industrial East and along the Atlantic seaboard.				Northeast Seaboard	1	1	
				Eastern Seaboard	5	5	
				Southeast Seaboard	9	3	5
				Gulf Coast Seaboard	3	3	
				Foreign Almirante (Panama)	1		
Industrial Locations:				Special Facilities for Marine Biological Studies:			
				Fresh Water Sites			
				Total Immersion:			
Northeast	3	1		Mississippi River	2		
East	24	14		Ohio River	2	1	
Southeast	1	1		New Kensington, Pa.	1	1	
Central	5	2		Montreal Harbor, Canada	1	1	
South-Central	2	1		Panama Canal	1		
West	1	1					
Southwest	1	1					
Rural Locations:				Total Number			
East	7	6		144			
Southeast	8	3	3				
North-Central	1	1					
Central	1						
South-Central	1						
Marine Seaboard Locations:							
Northeast	1	1					
East	6	4					
Southeast	9	5	4				
West Coast	1	1					
British Guiana, Pitcairn Island (British Oceania),							
Coco Solo (C. Z.), Almirante (Panama)	4	2					
Sea Water Test Sites (Marine)							
Total Immersion:							
Northeast Seaboard	2	1	1				
Eastern Seaboard	12	6					
Southeast Seaboard	10	3	5				
Gulf Coast Seaboard	3	2					
Northwest Seaboard	1	1					
Western Seaboard	2	1					
Southwest Seaboard	5						

NOTE: † signifies privately-owned sites, willing to exchange exposure facilities to a limited extent.

‡ signifies commercial test service.

* (Abstracted from "Survey of Exposure Test Facilities," by A.C.C.C., November, 1942).

Most of the above sites are used for more than one test program.

In addition to the above, the ASTM is conducting an extensive atmospheric exposure test on zinc-coated steel wire at eleven locations, as follows:

Pittsburgh, Pa.
Sandy Hook, N. J.
Bridgeport, Conn.
State College, Pa.
Lafayette, Ind.
Ames, Iowa.
Manhattan, Kansas.
Ithaca, N. Y.
Santa Cruz, Cal.
College Station, Texas.
Davis, Cal.

Three of these are included in above tabulations and are used for other tests, but the other eight have been selected exclusively for the wire test. Report of the ASTM Committee A5 (June, 1944) gives results of six years' exposure of these test wires.

The A.C.C.C. was originally organized to facilitate contacts with the British and other corrosion committees abroad (17). So far the work of the A.C.C.C. has included the compilation and maintenance of a directory of American corrosion investigators (now numbering about 500), their location, individual activities and interests. A list of American committees on subjects connected with testing and abatement of corrosion has been completed with a list of testing locations summarized in Table 1. The A.C.C.C. committee also administers grants towards research work on corrosion. There are several subcommittees investigating matters of interest to the members, including the question of centralizing and improving the bibliographies on this subject and the publication of a corrosion periodical. Some of the organizations represented on this committee have special facilities for furnishing details for the proposed current bibliography. It has seemed for some time that a periodical that would keep the hundreds of engineers interested in corrosion, well informed on current developments in that field, would serve a useful purpose. The main objective of such a periodical I believe should be to publish brief abstracts of current technical papers and reports; notices of approaching meetings, with programs; reviews of meetings recently held; and current news of interest to corrosion investigators. At present this information is widely scattered through several technical papers and there is no comprehensive bibliography.

In connection with the matter of

organization, the Electrochemical Society has gone a long way by establishing a separate division for the study of fundamental and general corrosion problems, a field for which many of their active members are eminently fitted. Last year the Society decided to compile a handbook on corrosion under the auspices of the Corrosion Division. This undertaking was delegated to a board consisting of the following members:

H. H. Uhlig, Editor	R. J. McKay
R. M. Burns	R. B. Mears
U. R. Evans	F. N. Speller
W. H. Finkeldey	L. G. Vande Bogart
F. L. LaQue	G. H. Young

The various chapters have been written by 95 investigators and engineers each of whom has made a special study of the subject assigned to him by the Board. This handbook will contain about 1,000 pages and will probably be published in 1945. Not the least important section of this book is a glossary of terms used in corrosion work with definitions agreed upon by the members of the Board and others after considerable debate. The royalties will be credited to the Corrosion Division of the Electrochemical Society for use in expanding its service in that field.

The meetings of the E.C.S. Corrosion Division are held each spring and they wish me to tell you that members of your Association are cordially invited to attend.

The NACE is to be congratulated on their enterprise and the progress already shown. Their contributions to the abatement of corrosion should do much to advance the art.

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Electrical Resistivity of Steel

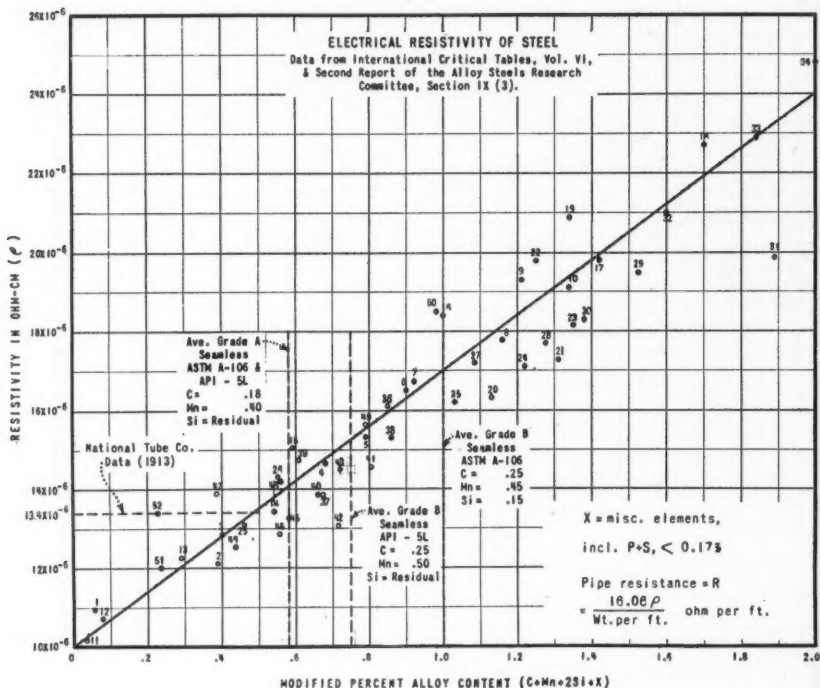
By R. P. Howell

Standard Oil Company of California

FOR a number of years, engineers engaged in electrolysis and cathodic protection measurements have used the tables of pipe resistance originated by the National Tube Company in 1913 and republished by the National Bureau of Standards in Technologic Paper No. 355. The factors are computed for a resistivity of 215.8 microhms per lb-ft (approximately 13.4 microhms per centimeter-cube). It is easily demonstrated that these tables are

not accurate for the "Grade B" and similar high-strength pipe being extensively used today, and as a result many engineers have developed their own approximate resistance factors.

The best available resistance data appear in the accompanying table and have been plotted on the accompanying chart to facilitate current measurements where it is not convenient to measure the resistance of an individual line, but where its approximate analysis is known. The



CHEMICAL ANALYSIS OF STEEL SAMPLES

KEY	P	C	Mn	Si	C+Mn+2Si	S	P	REMARKS	
1	10.95	0.019	0.025	0.006	0.056	0.004	0.012	25°C	$t_Q = 900^\circ\text{C}$
2	12.09	0.11	0.04	0.12	0.39	0.024	0.01	do	do
3	12.85	0.17	0.01	0.11	0.40	0.022	0.01	do	do
4	14.64	0.35	0.07	0.13	0.68	0.021	0.01	do	do
5	15.33	0.45	0.08	0.13	0.79	0.021	0.01	do	do
6	16.51	0.54	0.10	0.13	0.90	0.021	0.01	do	do
7	16.73	0.63	0.07	0.11	0.92	0.024	0.01	do	do
8	17.79	0.81	0.09	0.13	1.16	0.020	0.01	do	do
9	19.31	0.89	0.08	0.12	1.21	0.021	0.01	do	do
10	19.09	1.00	0.10	0.12	1.34	0.022	0.01	do	do
11	10.19	trace	0.036	-	0.036	-	-	18°C	$t_A = 950^\circ\text{C (vac.)}$
12	10.70	trace	0.074	-	0.074	-	-	do	do
13	12.24	trace	0.29	-	0.29	-	-	do	do
14	13.42	trace	0.54	-	0.54	-	-	do	do
15	15.04	trace	0.59	-	0.59	-	-	do	do
16	18.40	trace	1.00	-	1.00	-	-	do	$t_A = 1000^\circ\text{C (vac.)}$
17	19.81	0.22	1.08	0.06	1.42	0.05	0.10	19-25°C	do
18	22.72	0.33	1.27	0.05	1.70	0.05	0.09	do	do
19	20.90	0.17	1.09	0.04	1.34	0.05	0.09	do	do
20	16.32	0.23	0.89	0.005	1.13	0.01	0.058	do	do
21	17.27	0.36	0.87	0.04	1.31	0.09	0.08	do	do
22	19.80	0.36	0.80	0.047	1.25	0.04	0.10	do	do
23	18.17	0.41	0.72	0.11	1.35	0.041	0.039	do	do
24	17.10	0.37	0.73	0.06	1.22	0.04	0.09	do	do
25	13.10	0.06	0.38	0.01	0.46	0.035	0.017	25°C	$t_A = 930^\circ\text{C}$
26	14.30	0.08	0.31	0.08	0.55	0.05	0.029	do	do
27	17.20	0.23	0.635	0.11	1.085	0.034	0.034	do	do
28	17.70	0.415	0.643	0.11	1.278	0.029	0.031	do	$t_A = 860^\circ\text{C}$
29	19.50	0.435	0.69	0.20	1.525	0.038	0.037	do	do
30	18.30	0.80	0.32	0.13	1.38	0.009	0.008	do	$t_A = 800^\circ\text{C}$
31	19.90	1.22	0.35	0.16	1.89	0.015	0.009	do	do
32	21.01	1.22	0.12	0.13	1.60	0.019	0.01	25°C	$t_Q = 900^\circ\text{C}$
33	22.89	1.43	0.13	0.14	1.84	0.019	0.01	do	do
34	24.80	trace	2.00	-	2.00	-	-	18°C	$t_A = 1000^\circ\text{C (vac.)}$
35	16.21	0.28	0.65	0.05	1.03	0.06	0.083	19-25°C	do
36	16.09	0.16	0.66	0.014	0.848	0.03	0.074	do	do
37	13.83	0.10	0.55	0.024	.674	0.05	0.08	do	do
38	15.32	0.33	0.49	0.02	.86	0.05	0.068	do	do
39	14.73	0.144	0.46	trace	.604	0.08	0.09	do	do
40	13.86	0.16	0.48	0.01	.66	0.04	0.091	do	do
41	14.57	0.31	0.45	0.026	.802	0.04	0.10	do	do
42	13.07	0.28	0.42	0.008	.716	0.04	0.022	do	do
43	14.49	0.25	0.41	0.03	.72	0.04	0.10	do	do
44	12.87	0.16	0.38	0.009	.558	0.09	0.08	do	do
45	13.27	0.19	0.37	0.01	.58	0.05	0.09	do	do
46	12.53	0.215	0.22	-	.435	0.113	0.051	do	$t_A = 900^\circ\text{C}$
47	13.90	0.387	-	-	.387	-	-	do	do
48	14.20	0.559	-	-	.559	-	-	do	do
49	15.65	0.791	-	-	.791	-	-	do	do
50	18.50	0.981	-	-	.981	-	-	do	do
51	12.00	0.235	-	-	.235	-	-	do	do
52	13.40	0.227	-	-	.227	-	-	do	do

 t_Q = Quenching temperature t_A = Annealing temperature ρ = Resistivity in ohms per cm(10^{-6})

reports from which this material was obtained indicate that carbon and manganese in the usual amounts found in steel have about equal ef-

fects in increasing resistivity. Silicon has an effect approximately twice as great as equivalent amounts of carbon or manganese, but the silicon

content of most pipe is small. The line of average resistivity has been drawn on this basis. Recent typical analyses of Grade A and Grade B pipe have been obtained from National Tube Company and plotted on the chart. It will be observed that Grade A is the same for both American Society for Testing Materials and American Petroleum Institute specifications, whereas ASTM Grade B pipe has an appreciable silicon content by virtue of its being "silicon-killed." As a result, ASTM

Grade B has a somewhat higher resistance than similar API pipe.

These resistivities are of course not limited to pipe, but are applicable to any low carbon steel in the range of data used. The values plotted are for a temperature of 25 C; they will increase approximately six microhms per 100 degrees centigrade between 25C and 100C.

Grateful acknowledgment is made to Mr. A. E. Olson, who performed most of the work of correlating the data on which these results are based.

Economics of Mitigation of External Corrosion On Underground Pipe Lines

By J. Campbell Stirling

Stanolind Pipe Line Company, Tulsa, Oklahoma

THE economics of the mitigation of external corrosion on underground pipe lines has been an important problem to the pipeline industry for many years. In the United States there are approximately 333,000 miles of pipe line transporting crude oil, refined products, and natural gas, built at an estimated cost of \$3,200,000,000, which provide this nation with an underground transportation system that is a marvel to the rest of the world. The first crude oil pipe line was laid in 1865, the first gas line in 1876, and the first products line in 1930. Thirty years ago there were less than 60,000 miles of these pipe lines. Today there are approximately 133,000 miles of pipe lines carrying crude oil and refined products and approximately 200,000 miles of natural gas lines. On this system of underground pipe lines serving virtually every city and industrial center in the country, it is estimated there is an annual loss of \$50,000,000 resulting from corrosion. There have been adverse opinions on the value of corrosion mitigation; nevertheless, if sufficient and conclusive data can be correlated to prove definite and accurate answers to the following three questions, the economics of mitigation of external corrosion to underground pipe lines becomes apparent and sound.

1. What is the probable loss from corrosion if a pipe line is without any type of protection?

2. What is the probable loss from corrosion on the same pipe line if it has protection?

3. What would be the cost of pipeline protection?

It might be possible to develop a learned, technical article on the subject in which specific data and statistics would be presented in mathematical form; however, I do not have the inclination to prepare such a presentation. Rather, I should like to discuss the subject in a simple, clear manner and attempt to demonstrate that these answers may be obtained by the application of some experience, some knowledge, some common sense, and a wealth of sound judgment.

It should be understood that the term "Mitigation of External Corrosion on Underground Pipe Lines" includes all the phases of pipeline protection, corrosion mitigation, and control. Pipeline protection cannot be acquired without cost and it should be considered as an investment or insurance, not as an expense, and certainly not as a speculation. An investment in pipeline protection for corrosion mitigation, upon which the success of the larger investment in the pipe line itself may depend, is worthy of close scrutiny.

The probable loss to be expected from external corrosion depends on two factors:

1. How frequently leaks will occur. It is not enough to say that leaks will occur. For an intel-

ligent analysis, we must know how frequently they will occur.

2. What the loss will amount to when a leak occurs. The average direct labor cost to Company "A" was \$160 per leak on 10-inch and 12-inch lines over a 2½ year period from January 1, 1940, to June 30, 1942. This did not include cost of pipe for replacement nor the damage to property. The probable direct loss of oil is usually easy to determine. The amount of damages to stock, crops, land, and improvements, is readily arrived at by appraisal; however, considerable difficulty is commonly experienced when attempting to estimate damages to water supplies, irrigation ditches, and similar projects. The list of possible unknown damages could be prolonged indefinitely.

Exposures are frequently overlooked in estimating the importance of possible leaks. Let us consider two similar leaks. One of them occurs in an open pasture with nothing of important value near it. The direct loss in this case would be limited to the loss of oil, cost of repairs, and local damages. If the other leak should occur in a creek from which drainage enters the domestic water supply of some community, town, or city, the damage would likely be great and the cause apt to create inconvenience to many people resulting in ill feeling toward the offending company. In appraising these two areas with the intention of estimating justifiable pipeline protection, it would be obvious that the value of exposure in the second case

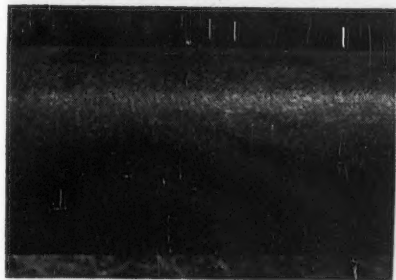
would be of vital importance, and the cost of protection which may be entirely proper for the second would be unreasonable for the first.

Goodwill is a valuable asset. It is one of those intangibles hard to define, yet it is often a large item of expense. Serious public damages may create ill will and are most likely to cause demands for extreme and costly settlements. Such payments are of course highly variable but must not be overlooked in the final analysis of losses. Two extreme cases which have been called to my attention concerned leaks that cost a company \$20,000 each. Serious exposures may result from oil leaks and even though insurance companies foot the bills, the oil and utilities companies meet the increase in insurance rates.

The aggregate loss should also include loss of pumpings or revenue which may occur as a result of station shutdowns caused by a leak. The physical loss created by the leak might be small but its influence on operations might be great. Estimates of such losses should include length of time necessary to restore the line to operation, and pumping which would be lost during that time.

Company "A" Case I

In 1923 this Company laid a pipe line from Teapot Dome, Wyoming, to Freeman, Missouri, a total of 715.68 miles. This system included the following pipe: 78.86 miles of 8-inch screw end lapweld 28.55 pounds per foot .322-inch wall thickness; 211.03 miles of 10-inch screw end lapweld 40.48 pounds per foot .365-inch wall thickness; 465.22 miles



Company "A," Case I, specimens of pipe buried 13 years ago. Bitumen and wrapper

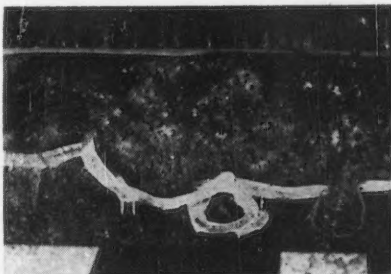
of 12-inch screw end lapweld 49.56 pounds per foot .375-inch wall thickness, which makes a total of 755.11 miles of pipe. Along three sections of the right-of-way two parallel 8-inch lines were laid which accounts for the mileage of pipe exceeding the length of the line.

Approximately 710 miles of pipe was given a single coat of bitumen without a wrapper when laid. The remaining 45 miles of pipe was coated and wrapped. Of the 45 miles, 19 miles was wrapped with a heavy hair felt, and 26 miles with 15-pound asbestos felt.

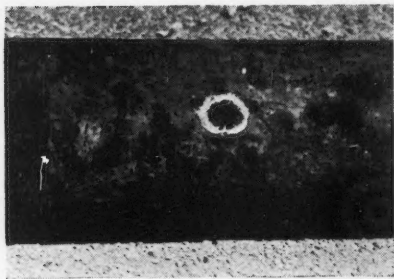
This line was operated as an oil line for several years. Then, that part of it from Welch Station near Glenrock, Wyoming, to Lawrence, Kansas, was used for transporting natural gas. During the 13 years that the line had been in the ground, it had developed many pit leaks and sections of it were in such poor physical condition that great quantities of natural gas were lost through the pit holes. On one 40-mile section the gas company estimated that 90 per cent of the gas placed in the line was lost. In the Spring of 1936, the owners of the line decided to move

storage oil from Welch, Wyoming, to Freeman, Missouri, thence to refineries. In order to do this, it was necessary that the pipe line and stations be rehabilitated. Realizing the line was in such a poor physical condition that it could not be used for transporting oil, the Company completed plans and began to take up sections of this line for reconditioning. The areas of known leaks, the presence of salt or buffalo grass, marshes, road crossings, and other doubtful areas were used as a guide for the inspection of the line. In areas where inspections revealed corroded pipe, the line was taken up each way from that area until good pipe was reached.

Of the 45 miles of pipe that was wrapped when the line was laid, approximately 15 miles was taken up. This pipe was taken up not because of its poor physical condition but because it was necessary to move it from highway and restricted areas to a new right-of-way. Very few pit holes were found in this 15 miles of pipe. The majority of the pits bore definite evidence that they were the result of holidays, improperly applied coating, or abuse in handling. It was the observation that pipe coated with bitumen and asbestos



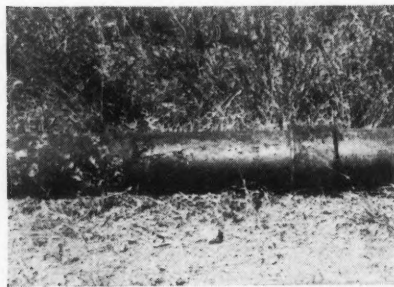
Pipe buried 13 years ago. Bitumen only



No protective coating. Pipe buried
13 years ago

felt was in excellent condition while adjacent to the wrapped pipe there was unwrapped pipe which was almost beyond recovery as many joints had 15 to 18 penetrations.

A total of 159.11 miles, approximately 21 per cent of the total pipe laid, was taken up, reconditioned in central yards, and relaid. Records of



Adjacent areas of bare and coated pipe

pipe classified in the cleaning and reconditioning yards revealed there were 4,018 penetrations or pit holes through the pipe wall. The total cost of the reconditioning of the 159.11 miles was \$1,262,000, which is equivalent to \$1.50 per foot. If the reconditioning cost of \$1.50 per foot were spread over the entire line that was

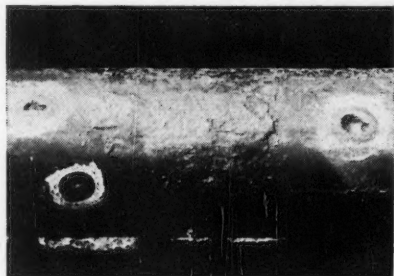
not wrapped when laid, it would be equivalent to \$.3366 per foot which was sufficient money at that time to apply adequate protection to the line, install cathodic protection, and meet electrical power costs for several years.

Realizing that steel will suffer deterioration when in contact with



Wrapped pipe handled with chain

corrosive soils makes it obligatory to coat any pipe laid along the right-of-way of this line. The use of pipe with sufficient wall thickness to withstand operating pressures without allowances for corrosion resistance would have permitted the saving of considerable tonnage of steel over the standard weight pipe that was used in the construction of this



Wrapped pipe placed on rocks in ditch



Cleaned pipe buried 13 years ago. Bitumen protected only

line. The use of coatings adequate to protect the pipe from corrosion as shown heretofore could be offset by the cost of reconditioning the line. In addition, the coating would permit the use of thinner wall pipe. For comparison in this case, we will use in our calculations $\frac{1}{4}$ -inch wall pipe. This system could be used for working pressures from 1,160 pounds on the 8-inch to 780 pounds on the 12-inch. The reduction in wall thick-

ness from standard weight pipe to $\frac{1}{4}$ -inch wall would have reduced the required tonnage of steel by 28,000 tons. The reduction of 28,000 tons at \$84 a ton (which was the average cost of pipe strung on the line) would have resulted in a \$2,352,000 saving.

In other words, if the money spent in 1936 for reconditioning 159.11 miles of the line had been used for coating the line at the time it was



Other samples of pipe, bitumen protected only

laid, at the end of 13 years the line would have been in good physical condition and there would have been an estimated saving of \$2,352,000 in steel alone. In addition to this saving, the construction cost would have been less, less damages would have resulted from leaks, and the ill will of many landowners and tenants resulting from oil leaks would have been avoided.

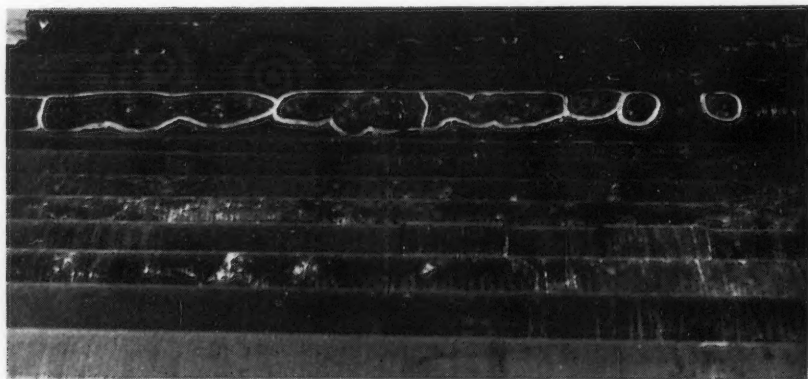
If the labor cost of \$160 per leak as shown heretofore were used as a basis for calculations, it would have cost \$642,880 in labor alone to have repaired the 4,018 leaks that actually existed in the line. In some areas where several pits were close together, the cost per leak would probably have been less than the \$160 average; however, there were many cases where other conditions would cause the cost to greatly exceed the average. Add to this \$642,880, the value of pipe necessary for replacement, the protective coating, and the property damage. The expenditure, if such a procedure had been followed, would probably have ex-

ceeded \$1,262,000, the cost for taking the pipe up, reconditioning, relaying, and coating it.

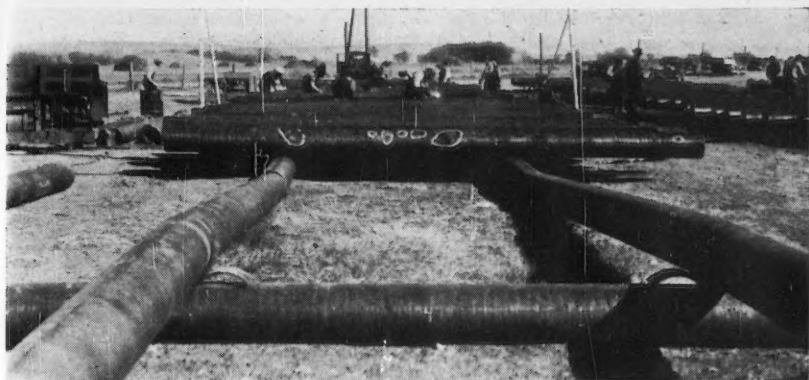
At the time of reconditioning in 1936, several sections of the line were returned to the ground with a single coat of bitumen, as the economic life of these sections was thought to be short. In the course of two or three years the economic status of those sections of the line changed from that of a temporary nature to a permanent nature. It was then necessary to recondition and wrap the line in these areas as the physical condition of the pipe became so bad the line could not be operated.

Case II

This Company recently constructed a 16-inch line from the Slaughter Pool in West Texas to Drumright, Oklahoma, on which it saved 8,573 tons of steel by using 351 miles of $\frac{1}{4}$ -inch wall pipe through areas of low pressure in lieu of .284-inch wall pipe. The reduced steel tonnage effected a saving of



Badly corroded areas in pipe buried for 13 years. Bitumen coated only



Reconditioning crew repairing pipe good enough for re-use

\$771,600 in the cost of pipe. Wall thickness of .284-inch has been used in this case as a basis for calculations because it was the maximum thickness required for the operating pressure of the line.

Protective coating was applied to the entire line at a cost of approximately \$963,000 and it is estimated that an additional \$57,000 would install cathodic protection. The total cost of protective coating and cathodic protection would be approximately \$1,020,000 which exceeds the actual saving in steel (\$771,600) by \$248,400.

Should the line have been laid bare and the same policy followed as in Case I, then the wall thickness of the pipe in this line would have been .375-inch. In this case the use of .250-inch wall pipe with coating would have effected a saving of 23,580 tons of steel valued at \$2,122,200 strung on the line. Then the cost of protective coating plus the cost of cathodic protection would have effected an estimated \$1,102,200 saving.

Case III

During 1944 this Company constructed approximately 232 miles of 12-inch pipe line from Elk Basin to Casper, Wyoming, on which pipe was used having a minimum wall thickness required by pressures to be handled. By reducing the wall thickness from .375-inch (standard pipe) to the minimum required for the pressures, there resulted a saving in steel of 5,240 tons valued at \$470,552 strung on the line. This saving in steel is \$200,000 more than the cost of the protective coating that was applied to the line. It is estimated that \$50,000 will cover the cost of cathodic protection to the line.

Case IV

In 1919 sixty miles of 8-inch screw-coupled pipe was laid bare from Devol to Healdton, Oklahoma. During 1925 and 1926 the entire line with the exception of $6\frac{1}{4}$ miles across two creeks, was raised, cleaned, and coated with bitumen

and a hand-applied wrapper of asbestos felt. In 1932 and 1933 the pipe across these creeks was replaced. In 1940 short sections of pipe at various hot spots equalling 8,900 feet and a six-mile section across creeks was replaced with welded, coated pipe.

Tests made show that this entire line can be cathodically protected for approximately \$36,000, which is only \$600 per mile. It is particularly adapted to cathodic protection because it is coated. Even though the

thickness of the pipe used in this line could have been reduced from .322-inch to .250-inch and the saving in steel would have been \$90,000 which would have been \$20,000 in excess of the estimated cost of a wrapped coating.

Company "B"

Case I

In 1926 and 1927, this Company laid 225 miles of 8-inch pipe between Kings Mill, Texas, and Ringling, Oklahoma. The line was double-



Grinding spot welds to present surface for protective coating

coating was applied in 1925 and 1926 when the methods were crude and workmen inexperienced, it would materially reduce the cost of cathodic protection by increasing the length of the line which could be protected by each unit.

This case is cited to show that even though the coating was applied poorly under adverse conditions and it has little value in eliminating pitting, it would materially reduce the cost of cathodic protection. The wall

coated and double-wrapped at a cost of \$265,000, which is approximately \$1,180 per mile.

Line was removed in 1942 and relaid from Corpus Christi to Damon Mound, Texas, as a supply line for a 24-inch diameter oil line from Texas to the Eastern Seaboard, known as the "Big Inch." A large portion of the pipe was relaid with the original coating intact, which is an economy as the major coating expense was for field joints, as would be the case



General view of central pipe-reclaiming yard

with factory or yard coated pipe.

It is claimed that the recovery of pipe from this line was near 100 per cent. Reports show there was no culling, no measuring of pits, nor junk pipe to be disposed of; pipe was like new.

In view of the behavior of the coating on this line, having provided it with positive protection for sixteen years, there is little doubt that the pipe could have been thin wall. The reduction of wall thickness from .322-inch to .250-inch would have effected a saving of 3,700 tons of steel at an estimated value of \$330,000 strung on the line. This saving in steel cost would be \$65,000 greater than the cost of the protective coating.

Case II

During 1941, this Company laid an uncoated 8-inch line between Casper and Welch, Wyoming. A recent inspection of this line showed that most of the pipe in low areas was pitted to some degree. One section, 2,500 feet in length, was observed

where the pitting was very severe and extended the full length of some joints. Many of these pits had penetrated more than one-half the pipe wall thickness. As this line has been laid only three years, the condition of the pipe indicates that many punctures would have occurred within the next three years. An adequate coating on the pipe similar to that applied on the line in Case I would have prevented severe corrosion, permitted the use of thin-wall pipe thus effecting a substantial decrease in the required tonnage of steel, and as a result of greater inside diameter increased the pumping capacity.

Company "C"

This Company, whose lines serve the Midwestern States, began its operations in 1930 by laying its lines bare. In 1937, when additional lines were laid, coating was applied to approximately 25 per cent of the pipe. The experience of this Company with corrosion has changed its policy to the extent that it plans on laying no more lines bare. The Cor-

rosion Engineer for this Company recently informed me and I quote: "Any lines we build in the future will be solid-coated, with cathodic protection. Since the cost of applying cathodic protection to a well-coated line is usually quite nominal and only an exceedingly small fraction of the overall construction investment, its use will be included."

Company "D"

Company "D" installed its original line in 1936 in Nebraska. It is our information that seven miles of this line east of Cozad was taken up and reconditioned in the Spring of 1938 because the physical condition of the pipe was so bad that the line could not be operated. Line was originally coated with a single application of material and not wrapped. When the pipe was replaced in 1938 it was again coated with one application of the same material and no wrapper. In 1940 some of the pipe was replaced a second time. It was wrapped this time and we have been

informed that no further trouble has been had with this section of the line.

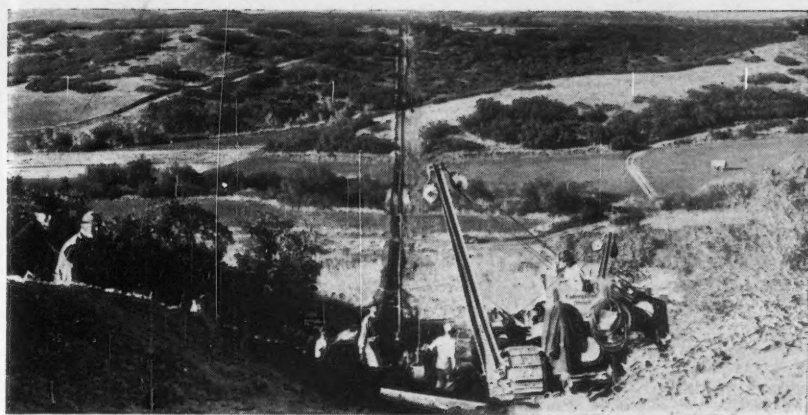
Other sections of the line were laid without any protective coating, on which cathodic protection was later installed. Several sections of the bare line, even though it has cathodic protection, have deteriorated to the point where it is necessary to replace them. Some sections as long as a quarter of a mile have deteriorated to a critical condition. A large portion of this line is parallel and adjacent to the line described in Case I of Company "A" which was reconditioned in 1936 and coated with bitumen and asbestos felt. The line belonging to Company "A" is serving well; therefore, it is believed that if the line of Company "D" had been coated and wrapped it would be giving equally dependable service.

Company "E"

A California Company reports after seven years service that examination of bitumen pipe-coating re-



Rocky and rough pipe-line right-of-way. A stream crossing and rough slope encourage slippage in trench



Alternate hills and narrow valleys present alternate wet spots and areas of abrasion

vealed it was apparently unchanged since application. No leaks had been experienced on the line nor had it been necessary to apply cathodic protection.

Company "F"

This Company reports that since previous inspections had indicated a wholesale failure of the original hot-enamel coating on an 18-inch line, it was agreed that an initial protective drainage of 1.5 to 2.0 milliamperes per square foot of pipe should be applied. When cathodic protection was applied, it was discovered that the former appraisal of the coating proved to be pessimistic and the pipe responded to protection much better than expected.

The findings in this case bear out other observations that in many cases even though a thin coating might furnish very little protection to the pipe against corrosion, it is a valuable asset to the application of cathodic protection.

General

The reduction of the wall thickness of pipe increases the capacity of the pipe line as follows:

Size	Nominal Thickness Std. Wt. Pipe	Thin Wall	Line Capacity Increase
8"	.322"	.250"	5 %
10"	.365"	.250"	6½ %
12"	.375"	.250"	6 %
16" O.D.	.375"	.250"	4½ %

Let us visualize what 6 per cent means in increased capacity. It could mean the reduction of \$300,000 or the laying of an additional twenty miles of 12-inch pipe on a \$5,000,000 project. This economy is to a great extent made possible by the use of adequate pipe line protection.

One engineer estimates that on pipe lines completed during 1941, his company participated in a saving of 35,000 tons of steel through the use of lighter weight pipe in conjunction with coating. This is more steel than is required to build ten average-size cargo ships. His experience shows savings of steel as high as 33 per cent through the reduction of pipe

weights from those previously used under similar conditions.

The reclaiming of pipe from existing lines becomes more important with each additional wartime demand for steel. Without protective coatings and cathodic protection, much of the used pipe would be worthless for relaying as the residual wall thickness is not sufficient to withstand corrosion.

Another engineer reports that, in recent instances involving the valuation of buried pipe to be taken up and relaid, fully protected pipe received valuations 35 to 50 per cent greater than bare or only partially protected pipe.

Protective coatings have been instrumental in the greatly increased use of steel pipe as the most practical material for water lines.

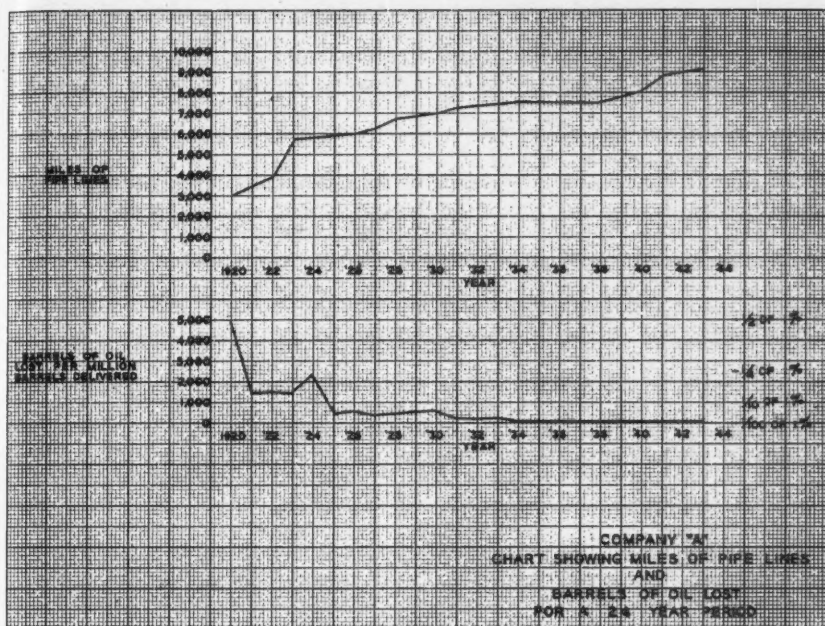
From the preceding information and data, it appears without a

reasonable doubt that protective coating is a conservative measure. During normal times its justification rested solely on economy; however, the uneconomic use of heavier than necessary pipe to retard corrosion in peacetimes becomes indefensible in the face of wartime steel shortage. Having determined the pipe wall thickness required to withstand the operating pressure, the pipeline engineer must choose between buying additional thickness of steel to forestall failure from corrosion or buying protective coatings.

The most destructive factor on coatings underground is probably soil stress. It is generally true that the thicker the coating the greater the efficiency and initial cost. However, the material is just as important as the thickness. Very thin coatings are of little value as a protection to pipe against pitting;



Line is being laid in trench from which rocks have been removed and cushion or mulch of loose soil prepared to prevent abrasion



nevertheless, experience shows they aid materially in utilization of cathodic protection.

Reinforcements or shields, whether asbestos, cotton, or rag, greatly improve the coating. Of these reinforcing materials, asbestos appears to be the only one in common use today which is invulnerable to deterioration in the soil.

In evaluating areas for purposes of estimating justifiable pipeline protection, it is quite apparent that the value of exposure in some areas would be of vital importance and the cost of extreme protection which may be entirely proper for them, out of reason for other areas.

Conclusions

In this discussion I have at-

tempted to relate the facts as I have found them. As pointed out in the beginning, it has been my object to demonstrate that the answer to the question, "Is the mitigation of external corrosion to underground lines economical?" could be obtained by the application of knowledge, experience, common sense, and judgment. I have not advanced any theories to account for the various types of corrosion, but I have tried to show that successful methods are already employed in combating it.

Since there are successful methods for combating corrosion, it permits the designing engineer to use steel of a thickness necessary to care for the working pressure, plus a safety factor. It is no longer necessary to add steel to the required thickness

of pipe to provide for the anticipated corrosion.

If I were to design a pipe line for my own use, it would be laid with pipe of the required wall thickness to withstand the operating pressures, plus a factor of safety. A substantial coating, tested for holidays, would be applied over the entire line. After the line had been in the ground for six months, the coating would be checked for discontinuities. It is entirely feasible through demonstrated means and at slight cost to locate and to repair discontinuities occasioned through construction. Subsequent to the test for discontinuities

of coating and repair of damaged areas, if additional protection were required, it would be obtained by cathodic means. In my opinion a pipe line of this design would be the most economical one possible to construct, as the initial cost would be low and corrosion maintenance would be negligible.

Acknowledgment

The assistance of several engineers who furnished data is acknowledged, but their names are withheld in order that their lines or other affiliations may not be identified.



Annual Meeting

The War Committee on Conventions has requested that all meetings of more than fifty persons be postponed until the need for restrictions which lessen the burden on transportation and services no longer exists. NACE wishes, of course, to cooperate with the committee to the fullest extent. It is considered possible, however, that a general meeting may be held during the latter part of this year but, if not, it will be held as soon as conditions justify it.

CORROSION and the "News-Letters" will be utilized to keep the members informed concerning the activities of the Board of Directors and special committees.



Use of Forced Drainage Systems in Stray Current Areas

By Eric G. Carlson

Plant Engineer—Transmission
The Bell Telephone Company of Pennsylvania

WHEN D.C. circuits are operated with a grounded return, as in the case of most electrified street railways, stray currents almost invariably find their way to the underground structures of other utilities such as water pipes, power and communication cables. Where stray currents enter a subsurface structure from the earth a measure of cathodic protection is obtained. However, these currents must eventually leave the structure to which they have strayed and when this occurs via the earth, the structure is attacked by electrolytic corrosion and is accordingly damaged.

In the case of lead-covered cables and pipe structures of good conductivity, the usual protection against this form of corrosion (anodic) consists of drainage wires and, of course, in some cases, insulation. The papers of Dr. J. M. Pearson* and Mr. A. V. Smith** describe the application of network calculations to this problem. By the use of such calculations, drainage wires can be designed and installed which will alleviate if not entirely clear any anodic exposure. Where the distances involved are short, drainage

wires are, generally, relatively inexpensive compared to the value of the plant protected and are quite satisfactory.

Where the anodic area is at some distance from a suitable point of connection, the cost of a drainage wire may be prohibitive due to the large cross section of wire necessary to meet resistance requirements. The cost may be further influenced by the availability of routes or construction facilities for such wires.

Use of Forced Drainage

When an anodic area is remote from the power source, the required drainage current is usually small, and may be considerably less than the current carrying capacity of required drainage conductor. It is in this type of situation that a smaller wire and an external emf to overcome the higher I R drop has an economic justification. This is particularly true when a local anode, either specially installed or a nearby rail, makes it possible to dispense with much of the wire.

A forced drainage system, as usually installed, is essentially a constant current system, with the result that the drainage current is never long in agreement with the drainage requirement. As a result, the connected plant is usually over-protected during long periods of the day and frequently other subsurface

* Electrical Instruments and Measurements in Solution of Electrolysis Problems, Bureau of Standard Corrosion Conference, 1937.

** Solution of Network Problems by the Use of Network Constants, Bureau of Standard Corrosion Conference, 1937.

structures not so protected are exposed to some measure of anodic corrosion.

Controlled Forced Drainage

The economic desirability and other advantages of forced drainage systems has led to the development of a method of control which largely eliminates the objectionable features discussed above. By means of network calculations and the use of the control network herein described, forced drainage systems may be designed and installed in stray current areas with the same engineering precision as heretofore associated with normal drainage wires.

In the following discussion, it is assumed that the positive terminal of all instruments are connected to the plant to be protected. It is also assumed that the galvanic potential, usually designated as alpha, is zero.

Theoretical Development of Required Rectifier Characteristic

Drainage current returned to negative bus.

initially, and ultimately to be permanently associated with the controlled rectifier.

Voltage reduction tests, internal resistance tests, and correlation tests are made in the usual manner and the following data obtained.

R_c = mutual or coupling resistance.

R_i = internal resistance, negative bus to cable.

R_b = resistance of interconnecting wires.

E_g = cable to earth potential.

E_b = cable to bus potential.

E_r = potential of rectifier.

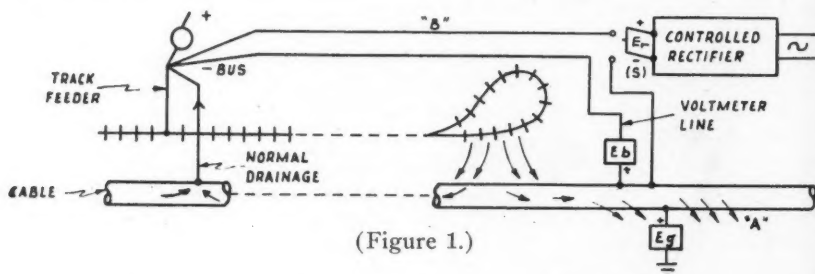
It is required to determine the characteristics of the proposed rectifier in terms of voltage and current output.

If Switch "S" is closed, the current I in the system would be;—

$$I = - \frac{E_b + E_r}{R_b + R_i}$$

The effect on E_g is to reduce it by the amount IR_c and for perfect drainage

$$E_g - IR_c = 0 \text{ or, using } (1)$$



(Figure 1.)

In Figure 1, the cable is exposed in the vicinity of "A" due stray currents which originate in the track system. It is proposed that a drainage wire "B," having a resistance " R_b " be installed for test purposes

$$E_g - R_c \frac{(E_b + E_r)}{(R_b + R_i)} = 0 \quad (2)$$

Solving (2) for $\frac{E_r}{E_b}$ we have

$$\frac{E_r}{E_b} = \frac{E_g}{E_b} \frac{(R_b + R_i)}{(R_c)} - 1 \text{ or } (3)$$

$$\frac{E_r}{E_b} = \beta \frac{(R_b + R_i)}{(R_c)} - 1 \quad (4)$$

where $\frac{E_g}{E_b}$ is replaced by the symbol β

If a local anode were to be installed at some point near "A," and the potential between the cable and local anode be designated E_b , equation 4, would still be valid, except R_i would be substantially the resistance to ground of the local anode.

Connection Made Near End of Rail

In Figure 2, it is assumed that the rail is to be the anode. In a case such as this, E_r will have to be sufficiently large to overcome the negative cable to rail potential in addition to the I R drop of the interconnecting wire.

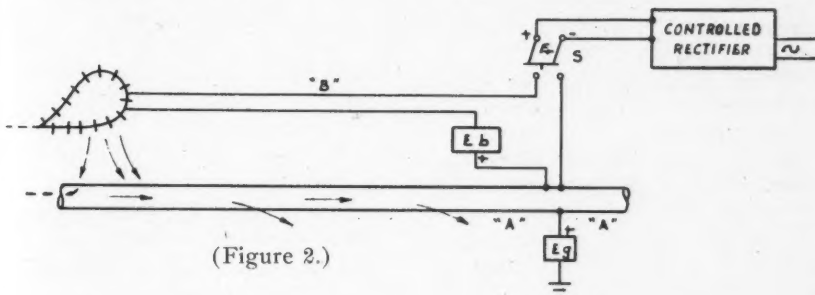
And since by design E_g is to be reduced to zero by IRc

$$0 = E_g - R_c \frac{(E_r - E_b)}{(R_b + R_i)} \quad (7)$$

and solving for $\frac{E_r}{E_b}$ we have

$$\frac{E_r}{E_b} = \beta \frac{(R_b + R_i)}{R_c} + 1 \quad (8)$$

Thus, when E_b is either positive or negative, E_r can be expressed as a linear function of E_b and its required maximum value determined for the maximum value of E_b as determined by test. The corresponding value of current can then be obtained from equation (1) or (5). Consideration of the maximum value of E_r and I will determine



R_b is again assumed to be fixed and E_b is now used as a negative quantity.

The other constants have the same significance as before.

With "S" closed

$$I = \frac{E_r - E_b}{R_b + R_i} \quad (5)$$

as before the change in E_g by I

$$= -R_c I$$

$$= -R_c \frac{(E_r - E_b)}{(R_b + R_i)} \quad (6)$$

the rectifier capacity and characteristic needed for satisfactory protection.

The ratio $\frac{E_r}{E_b}$ should be examined for each test point in the exposure and the rectifier chosen should meet the greatest required ratio. If this is done properly all test points in the exposure will be cleared of anodic potentials due to correlated stray current potentials.

Method of Control

Equations (4) and (8) indicate that to function satisfactorily a system of automatic control must maintain E_r at such a value that the relationship

$\frac{E_r}{E_b}$ is constant and a

function of the network constants regardless of the value of E_b .

The first objective in designing a control is to develop a means of determining when a change is needed in E_r (the rectifier voltage) to compensate for a change in E_b (the cable to bus voltage) and also to determine when equilibrium has been reached and no further change is needed.

Control Network

In the bridge circuit (Figure 3), the component parts have the following significance:

R_i represents the internal resistance between the structures to be interconnected.

E_b represents the open circuit potential between the structures to be interconnected.

R is an external resistance approximately equal to " R_i " (dependent on the sensitivity of the control device).

K is a constant in the order of 100.

R_t is a resistance equal to either

$$\frac{K(R + R_i)}{\frac{E_r}{E_b} - 1} \text{ or } \frac{K(R + R_i)}{\frac{E_r}{E_b} + 1}$$

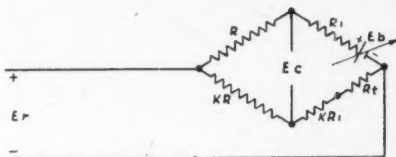
dependent on the polarity of E_b and is further discussed below.

In the bridge, if E_r and E_b are of such value as to meet the required

ratio of $\frac{E_r}{E_b}$ for a specific application,

E_c will be equal to zero. If E_b , which is independently variable, should change to another value, E_c would no longer be zero and its sign will be either positive or negative, dependent on whether E_b increased or decreased.

The voltage E_c can be made to actuate a mechanical or electronic device to bring about a change in E_r , in the proper direction, to restore E_c to zero, thus causing the ratio of E_r to E_b to again be consistent with the design requirement.



(Figure 3.)

Let I be the current flowing in the upper branch of the bridge. Then:

$$I = \frac{E_r - E_b}{R + R_i} \text{ and} \quad (11)$$

$$\frac{E_b}{I} = E_b \frac{(R + R_i)}{E_r - E_b} \quad (12)$$

The condition of balance for which $E_c = 0$ would then be:

$$R(KR_i + R_t) = K(R_i + \frac{E_b(R + R_i)}{E_r - E_b}) \quad (13)$$

from which

$$R_t = \frac{K(R + R_i)}{E_r - E_b} \quad (14)$$

$$= \frac{K(R + R_i)}{\frac{E_r}{E_b} - 1} \quad (15)$$

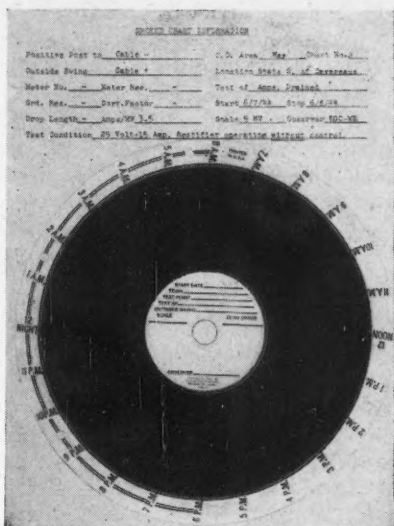
By similar reasoning if E_b were reversed R_t becomes

$$R_t = \frac{K E_b (R + R_i)}{E_r + E_b} = - \frac{K (R + R_i)}{\frac{E_r}{E_b} + 1} \quad (16)$$

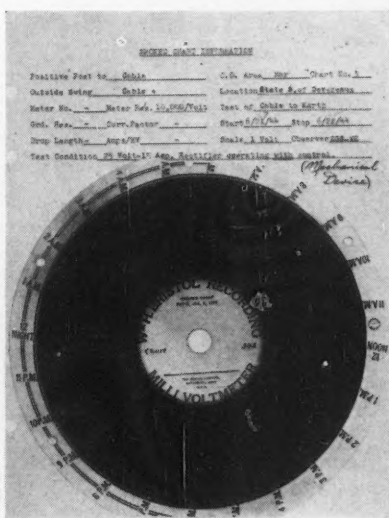
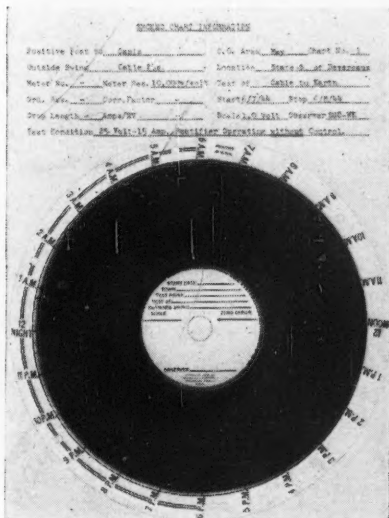
Since R_t reflects the relation between E_r and E_b , it can be shown that for any value of E_b , E_r and I meet the drainage requirements when E_c equals zero.

Results of Trial Installation

A trial installation of a forced drainage system was made in Philadelphia in a situation involving a severe "radial exposure" similar to Figure 2. The plant involved consists of two cables located about 22,000 feet from the power house and was exposed for distance of approximately 1,500 feet. A study of the data obtained from field tests indicated that it might be possible to



clear the exposure by installing a 4/0 drainage wire from the exposed area to the negative bus. The cost of an installation of this kind would



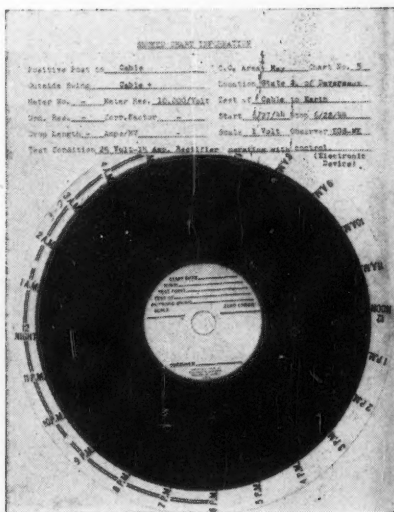
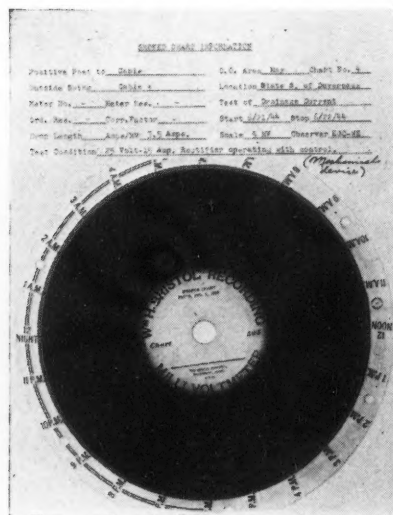
be in the neighborhood of \$10,000, without considering the cost of providing new conduit construction in several sections.

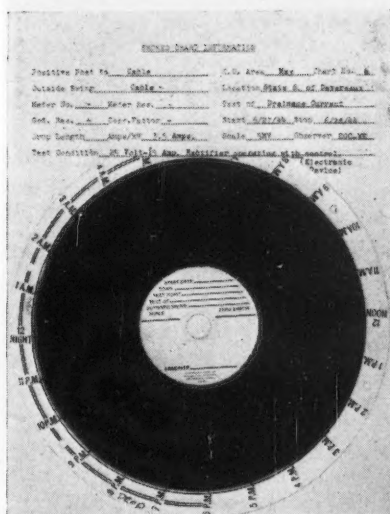
The possibilities of using forced drainage to a nearby rail were considered and it was found that at an initial cost of \$500 and a monthly charge of \$8.00 for power and maintenance adequate protection could be obtained. This appeared most attractive from an economic standpoint and accordingly a controlled rectifier installation was made on a trial basis.

The constants of the control network as described above were determined from the results of field tests and both mechanical and electronic means of controlling the rectifier output were tried, as well as permitting the installation to operate uncontrolled. Recording meter records were obtained for each

method of operation and are included in this paper as Charts 1 to 6.

Referring to the Charts and comparing the cable to earth potentials shown on Chart 1, without control, with those on Charts 3 and 5, with control, it will be seen that without control the sheath is more than one volt negative for about 10 hours (in order to obtain comparable charts, the same voltage scale was used for all records and the high negatives are somewhat greater than indicated, the pointer being against the stop), and slightly positive during the peaks. With control it will be noted that the potential to ground averages about 0.1 volts, negative, and is reasonably uniform. Comparing the drainage currents on Chart 2, without control and 4 and 6 with control it will be noted that the current, without control, is at a maximum when not needed and at a minimum when needed and that





with control the current follows the actual demands of the system.

Conclusion

Forced drainage systems, designed and controlled as described above, have the operating characteristics similar to normal drainage systems and are subject to the same limitations, in so far as their effects on other subsurface structures. When a local anode is to be used in connection with such an installation, the selection of the location for the anode must be made with considerable care in order to prevent adverse potential changes on other subsurface structures.

It is felt that the application of control to forced drainage make available to the electrolysis engineer a satisfactory method for reducing anodic exposures in areas which are difficult to correct by means of normal drainage wires.

Committee Activities

Meeting of NACE Condensate Well Corrosion Committee

A meeting of the Metallurgical and Test Container subcommittee of the NACE Condensate Well Corrosion Committee was held at the Rice Hotel January 22, 1945. The principal business of the committee was to determine the shape, size and method of arranging metal coupons in a test container to be installed in the high pressure flow lines of condensate wells producing corrosive fluids and to determine the metals and alloys to be tested.

After considerable discussion it was decided that the first necessary step in these tests was to determine by actual field test the proper method of arranging the coupons. Two designs were selected for this test from several which were considered. Each design will be made up in four inch XX heavy line pipe approximately 12 feet long. The specimens in one test container will be arranged as cylinders approximately three inches long spaced with short insulating cylinders to prevent metallic contact of the test cylinders. The test sections and spacers will present a flush joint smooth surface to the fluids handled. The specimens in the other container will have the form of annular rings approximately 1/16 to 1/8" thick and spaced with 1" thick insulating washers of greater internal diameter than the metal washers. This will promote greater turbulence than the first design. All the specimens in these two containers will be low carbon steel in order to determine the effect of specimen position on corrosion rate. The specimens will be tested in the flow line of a well producing corrosive fluid in the Cotton Valley, Louisiana field. It is hoped they can be completed within sixty days.

The second phase of the business consisted of discussing metals and alloys to be used in the tests. Some fifty of these were compiled but will be given further study and steps made to determine how many can be obtained for testing. It appears at present that the final list will be of the order of 50 to 60 different materials.

Galvanic Anode Committee

At meetings in Houston and Freeport, December 6 and 7, 1944, sponsored by the Dow Chemical Company, information was presented which indicated that magnesium holds promise as a material for cathodically protecting other metals from corrosion. It was reported by Dow engineers that many of the difficulties which were formerly encountered when magnesium was used as an expendable anode for the cathodic

protection of other metals have been overcome and that, under certain conditions, relatively high current efficiencies have been obtained from its use.

Members of NACE were present at these meetings and it appeared that the development of this method of corrosion control and the early distribution of technical data concerning it were of sufficient interest to our members to justify the sponsorship by NACE of a test program to outline the general field of usefulness of aluminum, magnesium, zinc and other materials which might serve as expendable galvanic anodes. Considerable data have already been collected. A test program of the various types of galvanic anodes conducted, correlated, and reported by an impartial body would, however, be of great help in making an early evaluation of the method of galvanic cathodic protection.

The nucleus of a committee on expendable galvanic anodes has been appointed, therefore, to develop such a test program and to obtain the cooperation of probable users and suppliers in making test installations. Data will be collected and summarized by the committee and reports issued as results become apparent.

Additional members are to be named to the committee. Suppliers of materials and interested users are urged to communicate with the Association.

F. W. Jessen, Director of Production Laboratories and Field Consultant for Petroleos Mexicanos, Mexico, D. F., visited Houston in the late fall of 1944 and attended the American Institute of Chemical Engineers in St. Louis.

Before going to Mexico Dr. Jessen served eleven years as supervisory engineer for Humble Oil and Refining Company. During that time his work was concerned with all phases of production, including corrosion encountered in production, natural gasoline plants and pipe lines.

His present work with Petroleos Mexicanos is concerned with the organization and installation of laboratories to serve the general production problems and field service work together with research in reservoir engineering, high pressure distillate fields, corrosion, plant operation, etc. A considerable amount of materials and equipment is available and much more is being obtained for the new laboratory. It is anticipated that much help will be given to present production and problems concerning corrosion.

Miss Geraldine Campbell, formerly chemist for Shell Oil Company Refinery at Houston, Texas, and one of the two women members of National Association of Corrosion Engineers, is giving up the study of corrosion for the present and taking up the art of home making. She was married to John H. Naschke on Feb. 10. They will reside in Houston.

N.A.C.E. Officers and Directors



President Brannon

Russell A. Brannon was born at Merit, Hunt County, Texas, December 22, 1902. He grew up on a farm and attended grade and high school at Merit and Dallas, after which he attended the University of Texas where he studied chemical engineering and business administration. He graduated in 1928 with the degree of

Bachelor of Business Administration. In 1928 he was employed by the Humble Pipe Line Company as chemical engineer, and now holds the position of Senior Corrosion Engineer with this company.

He married Mattie Lou Perry, on June 7, 1933, and they have a three-year old daughter.

Russell has been associated with the National Association of Corrosion Engineers throughout its organization and was elected its President in March, 1944. He considers this the accomplishment which he prizes most highly.



Vice President McElhatton

F. J. McElhatton, Superintendent of the Cathodic and Communication Department of the Panhandle Eastern Pipe Line Company, early in life became associated with the natural gas industry.

He was born in 1907 in Pittsburgh, Pennsylvania. Upon graduating from a technical high school in Columbus, Ohio, he was employed by the Ohio Fuel Gas Company on construction in the Transmission Department. Later while working in the Gas Control Department of that company, he attended the Ohio State

University where he received his degree in mechanical engineering and majored in electrical engineering.

He was associated with the Ohio Fuel Gas Company ten years, part of which time he was field supervisor on the construction of compressor stations, gasoline plants, and pipe lines. It was with this organization he first came in contact with corrosion control on pipe lines. In the fall of 1936, he accepted a position with the Panhandle Eastern Pipe Line Company to assist with the expansion program of the compressor stations. Upon completion of this program, he was placed in charge of the Cathodic and Communication Departments and has devoted the major portion of his time since then to corrosion studies.

For two consecutive years he acted in the capacity of vice chairman of the cathodic section of the Petroleum Industry Electrical Association. He is a member of the Electrochemical Society. His hobby is amateur photography which has resulted in many pictures of his two daughters.

O. C. Mudd is a native of Montana, having spent his early days on a cattle ranch near the copper mining metropolis of Butte.

He attended Montana State College at Bozeman as a student in electrical engineering until entry into military service in 1917 at the end of his junior year, serving for two years in World War I with a tour of duty overseas in the AEF, France.

He was employed by the Montana Power Company at Billings after the war with assignments to various duties in operation and construction,



Secretary-Treasurer Mudd



Director Corfield

during which time his hobby was amateur radio operation.

During 1925 he was employed by a contracting company in the vicinity of St. Louis as a superintendent of construction work involving municipal improvements, levee building and highway grading.

In 1928 he accepted a position with Shell at its Wood River Refinery and was transferred to the Shell Pipe Line Corporation in 1933 to assist in the first organized corrosion investigation on its system. He has continued in this work with Shell Pipe Line and is now Senior Corrosion Engineer.

Guy Corfield was born in Victoria, British Columbia, Canada, on Nov. 29, 1897, and lived in Victoria through high school. He then enlisted in the Canadian Army in 1915 and served with them overseas until

1919. During active service in France he was with the Signal Corps branch of the Canadian Army Engineers. After the Armistice he spent several months in the Army of Occupation on the Rhine.

Returning to Canada in 1919 he entered the University of British Columbia in Vancouver, from which he received a Bachelor of Science degree in Chemical Engineering in 1924. He then came to the United States and found employment with the Los Angeles Gas and Electric Corp., which later became the Southern California Gas Company. His initial employment with the gas company was as a chemist, which title was changed about five years later to research engineer a title he still retains. In 1930 he became a naturalized citizen of the United States.

His work has been almost entirely technical in nature, and considerably varied, with considerable stress on both internal and external corrosion of metallic equipment, and particularly external corrosion of pipe lines



Director Olson

due to burial in soil. This later subject has embraced all the various phases such as soil surveys, pipe coatings, electrolysis and cathodic protection, both from the research and operating standpoints. He has been a member of the American Gas Association and the Pacific Coast Gas Association and the California Natural Gasoline Association for many years; in 1933 he was Chairman of the Technical Section of the Pacific Coast Gas Association; for a number of years he has been an active member of the American Gas Association Subcommittee on Pipe Coatings and Corrosion. He has

served as Technical Editor of *Gas Magazine*, a Fuel Gas Industry trade journal, for a number of years.

G. R. Olson upon graduating from the University of Wisconsin in 1922 with a degree in Electrical Engineering, joined the staff of the Utah Power and Light Company and remained with that company until 1929. From 1929-34 he was with the electrical consulting division of the Electric Bond and Share Company, his work taking him to various properties of that company, a part of his time being spent in Mexico. In 1934 he was transferred to client companies in Bombay, India, where until 1939 he was general superintendent of operation and construction on the interconnected high-voltage electric power system serving that area. In March, 1939, he was placed in charge of the corrosion department of the



Director Pope

United Gas Pipe Line Company, Shreveport, Louisiana.

Robert Pope was born in Brooklyn, New York, on March 8, 1899. He was educated in public schools and at Stevens Institute of Technology, Hoboken, N. J., where he received a degree of Bachelor of Science in Mechanical Engineering in 1920. He was employed by Louis Lines Engineering Dept. of American Telephone and Telegraph Company in 1920 and was transferred to Dept. of Development and Research of A. T. and T. Co. in 1924. That department was merged with Bell Telephone Laboratories in 1934. He has been interested in corrosion problems on underground cables since 1920 and is now doing development work on new methods for detecting and preventing such corro-

sion. His principal hobby is photography.

He married Ruth Dorothy Edling on July 26, 1922. They have one son, Robert Charles, who is a navigator on a B-29 bomber stationed on Saipan.

Walter F. Rogers was born on April 3, 1905, in Tyler, Texas. He attended grade and high schools in Tyler, finishing in 1922. He received a Bachelor of Science degree in Chemical Engineering from the University of Pittsburgh in 1926 and degree of Chemical Engineer from that institution in 1934. He began work for the Gulf Refining Company in 1926 and transferred to Houston on a Mellon Institute Fellowship on oil production and pipe line corrosion problems for the Gulf Oil Corporation in 1927. This work was taken over directly by the Gulf Production Company in 1930. He has specialized in oil country corrosion problems, and is the author of several papers on corrosion which have appeared in the trade and technical press. He is a member of the API, A.C.S. and NACE. He is married, and has two children, Sharon, 8, and Nancy, 2.

Lyle Roberts Sheppard of Ferri-day, La., was born August 6, 1904, near Parkersburg, West Virginia. After spending his early years in Texas and Virginia he went with his family to Parkersburg where he stayed until he graduated from high school.

The next four years were spent studying general engineering at Carnegie Institute of Technology, Pittsburgh, Penna. When he finished in 1927 he worked for two years as office manager for the Northwestern Mutual Life Insurance Co. in Pittsburgh.



Director Rogers



Director Sheppard

In 1929 he accepted a position with Williams Bros., Inc., and began his pipe-line experience. This was the period when large diameter and high pressure pipe lines were

being built, on which he worked in Louisiana and the Middle West.

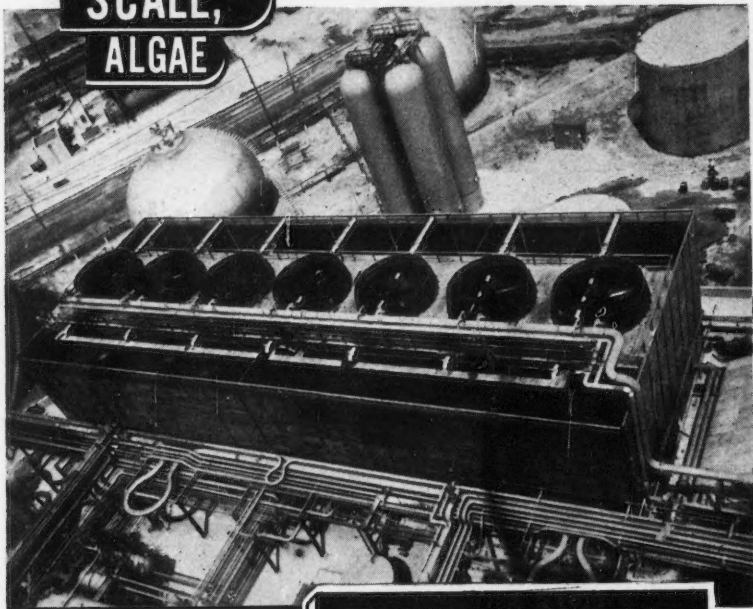
When Ford, Bacon & Davis started in the pipe-line contracting business in 1931 he went with them to East Texas and later to Tennessee.

In 1932 he started corrosion mitigation work for the Interstate Natural Gas Co., Inc., in Louisiana, at that time managed by Ford, Bacon & Davis. Working with O. C. Roddey he helped develop the distributed anode method of cathodic protection, since patented by Geo. I. Rhodes of Ford, Bacon & Davis. During this period he experimented with central ground beds, motor-generators, rectifiers, and various anodes (iron, graphite, carbon, zinc). At present he is doing experimental work on magnesium anodes, better measurement methods, and the relationship of the resistances involved in electro-chemical corrosion.

His hobbies are gardening, wood-working, and reading, but these are secondary to his family which consists of one wife, two daughters and one son.

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Corrosion Abstracts

GAS AND CONDENSATE WELL CORROSION

Cavitation as a Possible Cause of Internal Corrosion. D. T. MACROBERTS, United Gas Pipe Line Co., Oil Gas J. **43**, No. 20, 239-40 (1944) Sept. 23.

The problem of internal corrosion of oil well equipment has apparently increased since the deeper wells produce at much higher velocities and usually produce liquids along with the gas. This corrosion is particularly damaging in surface fittings and upper portion of tubing, and is noticeably concentrated at points of pressure reduction and changes in the direction of flow. Results obtained recently by Kornfeld and Suvorov of the Leningrad Physico-Technical Institute indicate that part of this metal loss is mechanical. The mechanism of cavitation and its destructive action are shown to be sufficient to warrant definite consideration in the problem of well equipment corrosion.

Causative Agents of Corrosion in Distillate Field. PAUL L. MENAUL, Oil Gas J. **43**, 27, 80 (1944) Nov. 11.

Evidence reported to indicate that organic acids may play a part in oil well equipment corrosion.

A Study of Corrosion in Gas and Condensate Wells in Katy Field, Texas. F. W. JESSEN, Oil Gas J. **42**, No. 52, 53, 54, 57, 59, 60 (1944). May 4.

Corrosion of High Pressure Well Equipment. THOMAS S. BACON, Natl. Petr. News **36**, No. 31, R 548 R 550-2 (1944) Aug. 2.

Corrosion of Bearing Alloys. L. M. TICHVINSKY, U.S. Naval Engineering Experiment Station, Annapolis. S.A.E. Journal **51**, 69-77 (1943) Mar. U.O.P. Abstracts **18**, 48 (1943).

The corrosion of bearing alloys by lubricating oils was investigated in the Underwood oxidation apparatus. Weight loss on bearings and properties of the oils were determined. The following bearing alloys were tested: Tin-base, lead-base, alkali-hardened lead, arsenic lead-base and silver lead-base babbitts; and cadmium-silver, cadmium-nickel and copper lead alloys. The corrosion was of two types—general and localized. Tin-base babbitt proved superior. Lead-base babbitts containing arsenic and silver showed promise. Value of adequate cooling of lubricating oil was emphasized.

Laboratory Evaluation of Corrosion Resistance of Bearing Alloys. L. M. TICHVINSKY.

Trans-Electrochem. Soc. **85**, 9-24 (1944) reprint 2. U.O.P. Library Bulletin of Abstracts, **19**, 128 (1944).

The Underwood, MacCoull and Sunbury tests for corrosion of bearing metals and oxidation of oils are described. Using these methods, tests have been carried out on the corrosion by seven oils of lead-alkali metal, lead-antimony-tin-arsenic, cadmium-silver, cadmium-nickel and copper-lead alloys. The results given by the different tests are not always comparable, but all are suitable for testing a range of oils with one alloy or a range of alloys with one oil. The lead-base babbitt containing arsenic has good corrosion-resistance, the attack being 5 times

that experienced with a tin-base babbitt. All other alloys are corroded much more, the cadmium alloys being the worst, and with these it is important to choose a non-corrosive oil to provide adequate oil cooling and to change the oil frequently.

Processing of West Texas Sour Crudes at Shell's Wood River Refinery. L. R. GRAY, Chief Technologist, Wood River, Illinois Refinery, Shell Oil Co., Inc.

Oil Gas J. **43**, No. 22, 73, 74, 77, 80, 97, and No. 23, 98, 101, 102, 105, 106 (1944) Oct. 7 and 14.

Also Petr. Ref. **23**, 388-394 (1944) Oct. Petr. Eng. **16**, No. 1, 160, 162, 164, 166, 168. Nat. Petr. News **36**, pt. 2: R 770 Nov. 1 (1944).

Data were obtained from operation of a 35,000-bbl. per day topping unit processing 100% West Texas crude. Discussion includes cracking operation. Corrosion rates for furnaces, piping, exchangers and fractionating vessels are given. Procedures for reducing the quantity of corrosive material and experiences with the use of liners and alloys to combat corrosion are related. The second article is concerned primarily with desalting crudes. Salt removal involves intimate mixing of the oil and water to form an emulsion and the subsequent breaking of the emulsion. Desalting is shown to reduce corrosion and decrease the cleaning of furnaces, heat exchangers and distillation equipment. Special maintenance and safety practices needed in processing sour crudes are given.

Six recent articles on the refining of sour crudes are cited by the Journal.

Some other articles dealing with sour gas and crude are:

Practical Elimination of Problems in Handling Sour Gas at High Pressures. FRANK B. TAYLOR, Oil Gas J. **43**, No. 13, 47 (1944).

How to Prepare for Sour Crude Processing. Natl. Petr. News **36**, No. 14, R 185-7 (1944).

Methods of Improving Sour Crude Petroleum Products. Natl. Petr. News, **35**, R 339-45 (1943).

Corrosion Control by Arc-Welded Stainless Steel Linings. W. W. McCLOM, Stone and Webster Eng. Corp. Natl. Petr. News, **35**, R 10-14 (1943).

Hazards and Corrosion with Sour Crudes. W. L. WILSON, Prof. of Petroleum Refinery Engineering, Univ. of Tulsa. Oil Gas J. **43**, No. 32, 107 (1944) Dec. 16.

The Principles of Electrolytic Corrosion of Metals. GEOFFREY E. COATES, Magnesium Metal Corp., Ltd. Chem. and Ind. **1944**, No. 35, 306-9. U.O.P. Abstracts **19**, 157 (1944).

A corroding metal may lose its negative charge (1) by the discharge of positive ions in solution, commonly hydrogen ions, to form pure hydrogen, (2) by reaction with oxidizing agents forming negative ions i.e. hydroxyl ions, or (3) by metallic conduction to another electrode at which (1) or (2) may take place. The presence of air or oxygen accelerates the corrosion rate. If the dissolution of iron, the anodic process, and the reaction of electrons with oxygen, the cathodic process, take place at sites well separated, the corrosion product will be loose and no hindrance to further corrosion. If conditions are such that a closely adhering product forms, par-

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ticularly over the anodic area, the corrosion rate may become very slow.

Over-voltage plays an important role in corrosion rate, i.e. cadmium dissolves very slowly in non-oxidizing acid because of the high hydrogen over-voltage. Hydrogen over-voltage is an important factor in corrosion of aluminum and magnesium.

Materials of Construction for Chemical Engineering Equipment. Chem. and Met. Eng. **51** No. 9, 93-136 (1944) Oct. No. 10, 134 (1944) Nov.

Chem. and Met.'s 11th report on this subject includes survey of corrosion experiences in the process industries; a directory of metals as materials for chemical engineering equipment including primary purpose of the material such as corrosion, heat or abrasion resistance; the corrosion resistance of metals to 88 different chemicals and solutions at various strengths and temperatures; a section on non-metallic materials including structural carbon, chemical stoneware, porcelain, acid-proof brick, glass, plastics, rubber and wood. The section on plastics lists effects of 21 chemicals on 14 varieties.

Lead Coatings on Steel. HAROLD A. KNIGHT, News Editor, Metals and Alloys, **20**, 1296 (1944).

A leading wartime development in the metal-finishing field has been the evolution and wide application of lead-alloy coatings for steel. Originally a conservation measure to save tin, zinc, chromium, etc., lead coatings (especially certain specially formulated lead-alloy coatings) have often proved superior in their own right and lead-coated steel has thus

become of outstanding interest to designers seeking economical, easily workable and corrosion-resistant materials for many types of postwar products. This article describes the coatings (both hot-dipped and electrolytic) and discusses their engineering properties and applications.

Restoring Corroded Plug Valves by Surface Arc-Welding. Nat. Petr. News **36**, pt. 2, R 744 (1944) Nov. 1.

Plug valves that had become corroded and sticky through contact with acid are being reclaimed through the use of electric arc-welding. Steel surface is machined down, desired metal applied and plug is machined to proper dimensions.

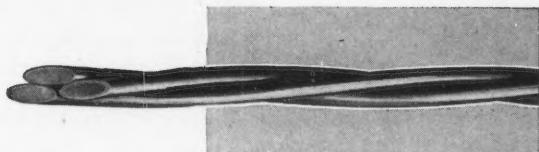
Special Corrosion Problems in Aircraft. W. E. DONALDSON, Chief Process Eng., Factory A., Lockheed Aircraft Corp., Burbank, Calif., Mech. Eng. **66**, 799 (1944).

Aircraft corrosion may be classified as follows: A. Corrosion caused by direct chemical action—(1) spilling of battery water during charging, (2) leaching of sodium sulfite from packing cartons around spare parts, (3) decomposition of trichloroethylene used in degreasing parts. B. Corrosion caused by dissimilar-metals contact—steel and magnesium, aluminum and steel, aluminum and copper, etc. C. Concentrated corrosion-cells. Aircraft engineer works to prevent completion of an electrical circuit between dissimilar metals or in a concentration cell. Anodizing of aluminum is very beneficial.

Water Chemists Meet in Pittsburgh, Power Plant Eng. **48**, 120 (1944) Dec.

Industrial water specialists presented data on the problems of dealkalizing, demineralizing, removal

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of ammonia, cooling water treatment, cathodic protection, treating plants for industries, treatment with lime and limestone, sterilizing with ozone and coagulation with silicates at 5th annual Water Conference.

The Use of Cyclohexylamine in Steam-Heating Systems. A. A. BERK, U.S. Bur. Mines, Rept. Investigations 3754, 42 pp. (1944) C. A. **38**, 5788 (1944).

Corrosion of steam-heating systems is due principally to CO_2 which acidifies the condensate. Cyclohexylamine was studied as a possible amine for neutralizing this acidity. Large quantities required because of high volatility of amine which resulted in loss at vents. Was effective in helping reduce return-condensate corrosion.

Pipe Protection on the Big Gas Line. STARR THAYER, Consulting Engineer. Petr. Eng. **16**, No. 2, 188, 192, 194, 196 (1944) Nov.

The selection of materials, coating procedures, method of application and coating inspection are discussed. Very satisfactory coating was obtained due to cooperation of inspectors and contractors. Cathodic protection for the line is in progress.

Plastic Coating Used to Prevent Corrosion of Oilfield Equipment. E. H. SHORT, JR., Oil Gas J. **43**, No. 30, 59, 61 (1944) Dec. 2.

A 4,535-ft. string of plastic-coated pipe has been installed in an East Texas salt-water-disposal well. The tubing was handled by ordinary methods without injury to coat. The plastic coat adheres strongly to clean steel. After cleaning, the steel is coated (0.005 in.) by 4 separate dipping and baking operations.

The Mechanism of Failure of 18 Cr-8 Ni Cracking-Still Tubes. C. L. CLARK, Research Metallurgical Engineer, Timken Roller Bearing Co., Steel Tube Division, Canton, Ohio, and J. W. FREEMAN, Research Engineer, Dept. of Eng. Research, Univ. of Mich. Nat. Petr. News **36**, No. 49, R-854 (1944) Dec. 6.

A metallurgical examination was made of 18 Cr-8 Ni cracking-still tubes which had been in service for time periods ranging up to 97,520 hours. In the "as-service" condition these tubes possessed entirely different characteristics; for (a) some were still ductile on the basis of the flattening test, (b) others were brittle but could have their ductility restored, while (c) others were permanently brittle.

On the basis of the results obtained, it is believed that the deterioration, and possible actual failure of 18 Cr-8 Ni cracking-still tubes in service is due to structural changes at the grain boundaries which are progressive in nature and are dependent on time, temperature and stress. These structural changes consist first of the precipitation and growth of highly alloyed ferrite due to the decomposition of austenite.

When these precipitated areas have grown to a certain size, cracking, at first nearly submicroscopic in nature, will occur under certain conditions of time, temperature and stress. When this cracking has occurred the tube is permanently brittle but at any time prior to the cracking the tube either is ductile or can have its ductility restored.

Stress-Corrosion Testing of Aluminum Alloys. G. WASSERMAN. Z.

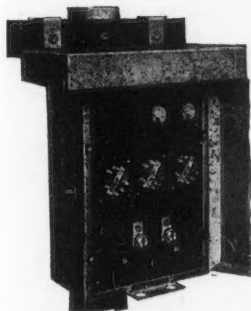
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Metallkunde **35**, 79-84 (1943). C. A. **38**, 3238 (1944).

The Stress-Corrosion Behavior of Al-Zn-Mg Alloys After Thermal Treatment. WALTER BUNGARDT and GUNTHER SCHAIBERGER. Z. Metallkunde **35**, 47-55 (1943). C. A. **38**, 49 (1944).

Intergranular Corrosion of Cr-Ni Steels. L. SCHAEFER. Korrosion u. Metallschutz, **19** 44-6 (1943). C. A. **38**, 3239 (1944).

Intercrystalline Corrosion and Its Dangers. LEIF TRONSTAD. Nord. Kemikermode, Feb. 5, 74-95 (1939). C. A. **38**, 1722 (1944).

Stress Corrosion of Metallic Materials. G. WASSERMAN. Chem. Fabrik **14**, 323-7 (1941); cf C. A. **36**, 2830; **37**, 2692, 3039, 4358, 5689, 6632; C. A. **38**, 5192 (1944).

Stress-Corrosion Cracking of 70-30 Brass by Amines. H. ROSENTHAL and A. L. JAMIESON. Am. Inst. Mining Met. Engrs., Inst. Metals Div. Tech. Pub. No. 1660, 9 pp. (1944). C. A. **38**, 1462 (1944).

Stress Corrosion Cracking of Austenitic Stainless Steels Types 347 and 316. M. A. SCHEIL and R. A. HUSEBY. Welding J. (N. Y.) **23**, 361s-3s (1944).

The behavior of Types 347 (18-8 Cb) and 316 (18-8 Mo) ferrite-free stainless steels was compared with that of Type 317 (25-33% estd. free ferrite). Three solns. were used, 42% CaCl_2 ; 42% $\text{CaCl}_2 + 0.1\% \text{HgCl}_2$; and MgCl_2 . The outer fiber stress was $40,000 \pm 5000$ psi. The soln. contg. HgCl_2 was not a good test medium because of the nature of the pitting attack. The 42% CaCl_2 soln. cracked the ferrite-free Types 347 and 316 but not the ferrite contg. Type 317. However, when pure CaCl_2 was used the results were negative. The MgCl_2 soln. at 154° cracked all 3 materials in about the same time although the cracking was less severe in the 317.

First Report on Stress-Corrosion Cracking of Stainless Steel in Chloride Solutions. M. A. SCHEIL, et al. Welding J. (N. Y.) **22**, 4935-5065 (1943). C. A. **38**, 49 (1944).



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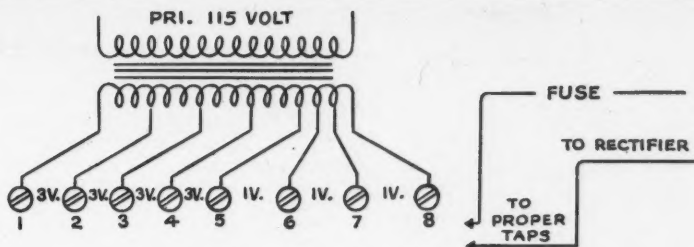
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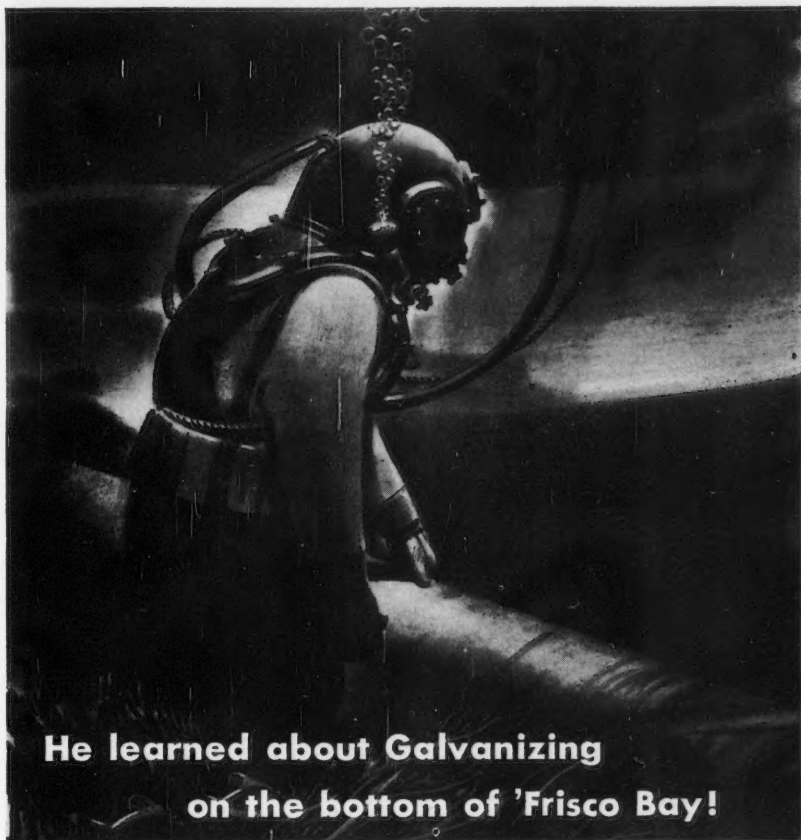
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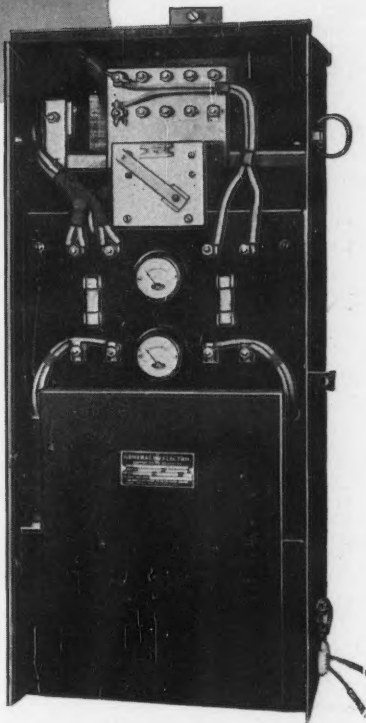
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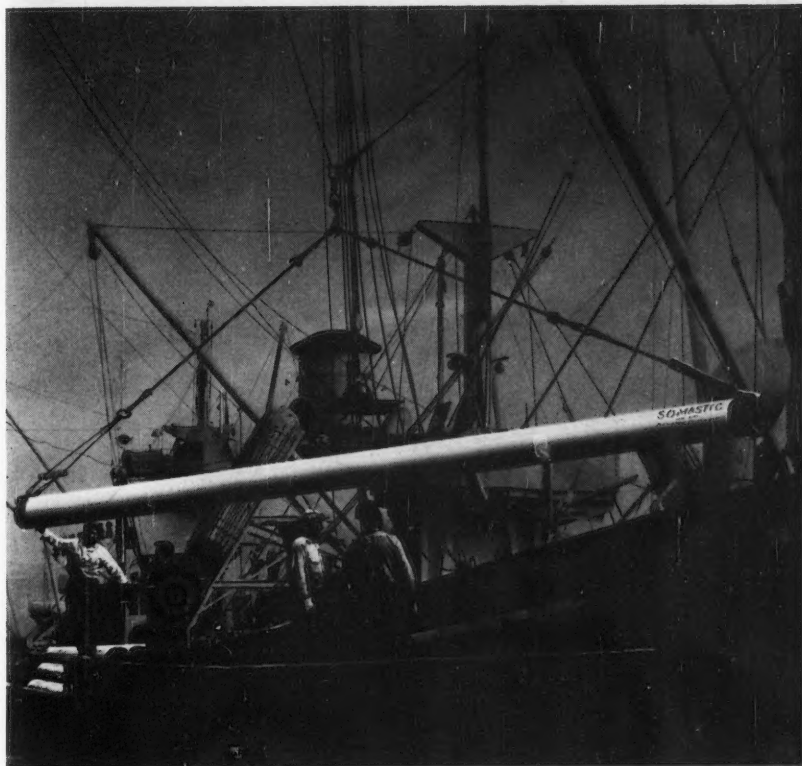
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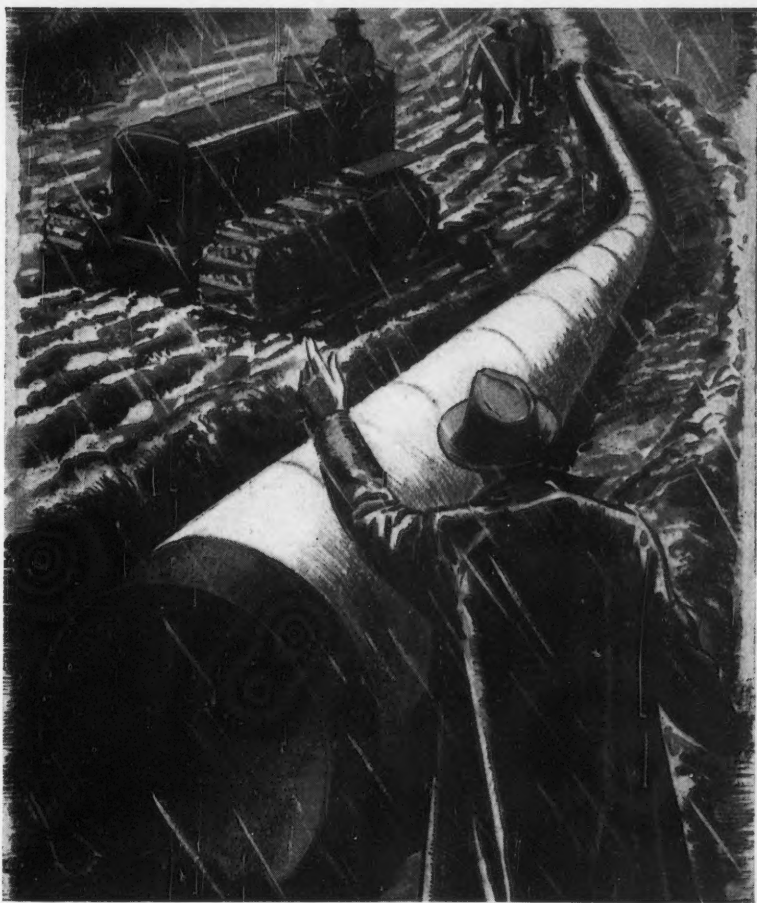
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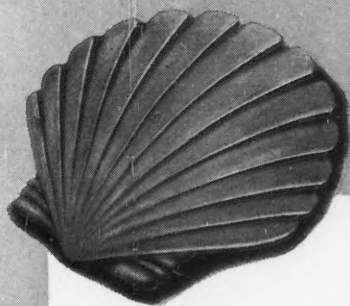
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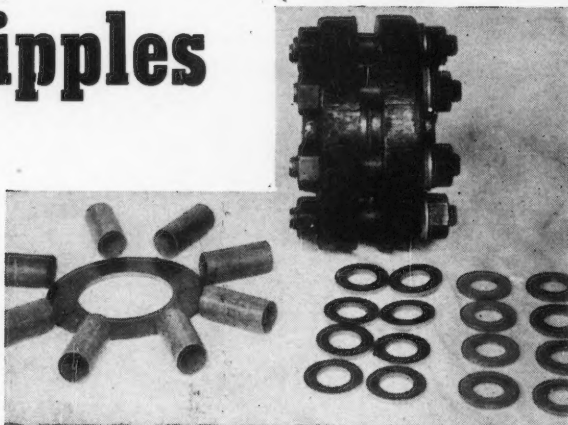


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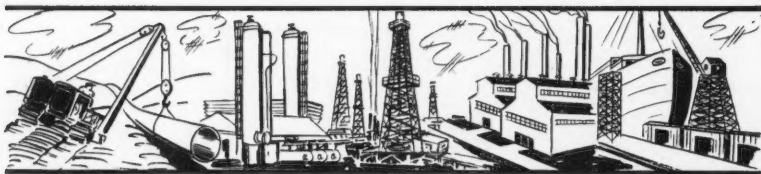
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PIPE LINE EQUIPMENT

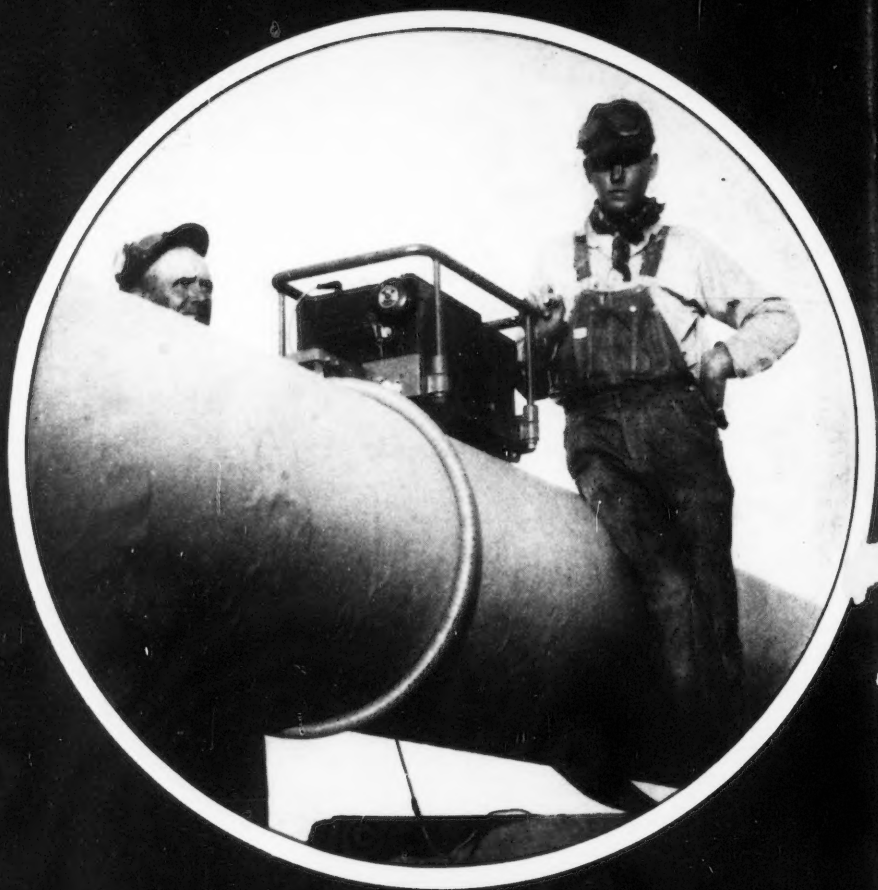


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